Stochastic Energy Deployment Model (SEDS) Project Review: NREL's Response and Reviewers' Report

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Acknowledgments

The SEDS team would like to express its appreciation to the reviewers who participated in the review of SEDS conducted in 2009. Their insights have already provided a basis for improvements to the SEDS model. The team is also indebted to the US. Department of Energy (DOE) sponsors of SEDS, Darrell Beschen, and Sam Baldwin, who have provided unfailing support both in initiating SEDS development and in supporting its continuing evolution and use.

Executive Summary

The Stochastic Energy Deployment System (SEDS) model has reached a point at which it can begin to examine future energy scenarios and the uncertainty associated with them. At this point, the model provides insights on future energy market uncertainties. To enable SEDS to meet the long-term objectives for its use as a research and development (R&D) planning model, further development of technology and policy options and of data breadth, depth, and validation are discussed in this working document. To help the SEDS team[1] move forward most effectively, 13 reviewers conducted a mid-course review of the SEDS model on May 7-8, 2009.[2] In the report of their findings (Section 3), the reviewers documented a wealth of valuable comments on needed improvements to the model.

In this working document, the SEDS team responds to those comments. The responses range from reporting on completed efforts associated with implementing a reviewer

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[1] The SEDS team at the time of the review was comprised of the following individuals:
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James Milford, lead developer (National Renewable Energy Laboratory)
Chris Marnay, buildings lead (Lawrence Berkeley National Laboratory)
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Dallas Burtraw, Resources for the Future
Jeff Harris, Alliance to Save Energy
Robert Hugman, ICF Consulting
Hill Huntington, Stanford University
Revis James, Electric Power Research Institute
Andy Kydes, Dept of Energy/Energy Information Administration
Michael Leifman, General Electric
John Maples, Dept of Energy/Information Administration
Anthony Paul, Resources for the Future
Bill Pepper, ICF Consulting
John Reilly, Massachusetts Institute of Technology
Constantine Samaras, Carnegie Mellon
Robert Wallace, Penn State

recommendation to providing a rationale for leaving SEDS as it is with respect to a reviewer recommendation. In between, there remain many reviewer recommendations that the SEDS team is continuing to investigate for either feasibility of implementation or alternative approaches. For example, two of the primary reviewer recommendations—that SEDS solve for equilibrium and modify the market share algorithm—are being investigated (equilibrium) or implemented (market share algorithm).

Some recommendations have already been completed; others may require a year to complete. The review process for SEDS is not expected to terminate with these improvements; additional formal reviews will be conducted, peer reviews of analysis will be performed, and additional SEDS publications will be produced.

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1 Introduction

The team represented by the authors of this working document has developed the alpha version of the Stochastic Energy Deployment Systems (SEDS) model. SEDS is a long-term model of U.S. energy markets with the unique characteristic that it explicitly treats uncertainty and is designed for eventual widespread use. For more information, see https://seds.nrel.gov/.

On May 7-8, 2009, a mid-course review of the Stochastic Energy Deployment Systems (SEDS) model was conducted by 13 reviewers. In the report of their findings (Section 3 of this document), the reviewers documented a wealth of valuable comments on needed improvements to the model. In Section 2, the SEDS team responds to those comments.

The SEDS team appreciates the value of the comments on the SEDS model provided by the reviewers. The team has already addressed some of the comments, is addressing others, and plans to address more of them. This document is intended both to help the SEDS team focus and prioritize its efforts, as well as to inform the reviewers and DOE of the team's response efforts.

Since the review, the SEDS team has been involved in other non-SEDS tasks, conducted some initial testing scenarios for DOE with SEDS, and investigated the feasibility of different courses of action in response to the reviewers' comments. Therefore, the responses to the reviewers' comments include what has been done, what is being done, what will be done, and what will not be done. The SEDS team anticipates this response will lead to additional ongoing discussion among team members, the reviewers, and the DOE sponsors; the team hopes this discussion will lead to a better SEDS model.

Fortunately, there were a large number of reviewer comments on SEDS. These comments can be parsed into two levels. The most important comments from the review panel are included in the body of this document. Additional comments from individual reviewers are provided in footnotes and appendices to the reviewers' report (Section 3).

The SEDS leadership team read all comments in the reviewers' report as well as notes prepared during group discussions by reviewers and SEDS team members and notes authored solely by SEDS team members. The SEDS leadership team gleaned many insights from the review and has, is, and will be acting on many of them. This document focuses on the comments deemed most important by the reviewers themselves. In particular, it focuses on the reviewer comments that appear in the body of the reviewers' report. More specifically, while all comments in the body of the reviewers' report are addressed here, highest priority is given to the five comments the reviewers explicitly called out as "important," including:

1. SEDS should solve for an equilibrium solution.
2. The SEDS market share model needs to be well estimated and consider behavioral factors and future expectations, especially in the electric sector.

3. SEDS should have some form of foresight built into it.
4. The model needs a decision-theoretic approach.
5. Realistic technology costs are needed in SEDS.

Section 1 introduces this document. Section 2 presents (1) the SEDS team’s responses to individual comments from the reviewers, (2) the SEDS team’s conclusions, and (3) the timeframe for each response (Table 1). Section 3 presents the reviewers’ report. The appendices are appendices to the reviewers’ report.

2 SEDS Team Response

This section is organized by individual comments from the body of the reviewers' report (Section 3). Presented first are those issues or comments that the reviewers deemed "important." These are followed by additional comments made by the reviewers. For each comment, (1) the comment is either quoted from the reviewers' report or paraphrased; (2) the comment is placed in the context of the model development process; (3) a SEDS team response is given and difficulties are identified for any implementation activities; and, (4) a timeframe for completion of such activities is presented. The SEDS team member who led each response is identified by last name in the subsection header, e.g., (Short). At the end of this section, we present our conclusions and the timeframe for our response to each recommendation.

2.1 Responses to Issues Deemed "Important" by Reviewers

2.1.1 Equilibrium (Short[3])

Reviewers' Recommendation

> The failure to solve for equilibrium in each period is a serious problem. The review team identifies this point as among the most important. The non-convergence creates more difficulties in interpretation when the stochastic version is used.
>
> Some reviewers feel that the non-equilibrium nature of SEDS, or at least the lack of a theoretical basis for disequilibrium within the model, renders the solution a truly random outcome that is not useable to inform R&D decisions.
>
> I'm not convinced that the model's being neither a general equilibrium tool nor purely a decision analysis tool is necessarily problematic, and would endorse Hill Huntington's suggestion that some rough approximation of price feedback may be a fruitful middle ground. I do agree that the model does not have adequate structure to capture disequilibria and thus markets need to balance [Michael Leifman; Appendix C7]

Model Development Context

In the early stages of SEDS development, the SEDS team deliberately minimized computer run time by having SEDS seek—but not necessarily reach—equilibrium as it moved from one year to the next. Initially, we planned to have a user-specified "time step" that could be **used** to test the accuracy of this approach by examining smaller time steps to see whether multiple iterations within a year yielded different results. In the course of the development effort, the flexible time step was abandoned in favor of simplicity.

[3] Principal author and point of contact for this response item

SEDS Team Response

We agree that the impact of the absence of equilibrium needs to be measured and, if found to be significant, resolved. We believe it may be possible to construct a special version of the model that iterates within each one-year time step until equilibrium is reached. To quantify the impacts of equilibrium, we will compare the results from this version with results from the existing non-equilibrium version for several widely different scenarios. If the impacts are not large, we will continue to develop the non-equilibrium version; if the impacts are large, we will develop an equilibrium version.

Difficulties with the Proposed Response

It is not 100% clear that we will be able to develop an equilibrium solution to SEDS without major rewriting of the code. In that case, we will consider the alternative step of examining short sub-year time steps, which also presents some difficulties.

If the equilibrium or small-time-step version is developed, the comparison with the non-equilibrium version will not be straightforward. Decisions will have to be made on which outputs to compare, at what point(s) in time, and what level of accuracy is required. It must also be decided which scenarios should be used for the comparisons.

Timeframe for Resolution

This is a significant undertaking. We expected it to require approximately six labor months of effort and to be completed by December 2010.

2.1.2 Market Share (Roop)

Reviewers' Recommendation

> SEDS needs a much better market share/market diffusion formulation/technology choice formulation than the one used in the electricity market and perhaps elsewhere since the current version cannot be calibrated well enough to simulate technology choices in the energy market; important non-price factors and consumer preferences are not represented in most, if not all, of the current choice functions. Without making this correction it is unlikely that the SEDS model can be reliably used for technology assessment.
>
> The current lack of accounting for behavior or institutional barriers to adoption limits the model's usefulness. For example, technology adoption could be hampered by a limited workforce, a "not in my backyard" social response, or other aspects of consumer/investor decision-making, etc.

Model Development Context

The adoption of a widely used approach to calculating market shares is consistent with the approaches taken in many other models, most notably, the National Energy Modeling System (NEMS). The second paragraph of the above reviewers' recommendations and the longer comments by Andy Kydes (see Appendix C.3) suggest that the method could be improved upon by accounting for institutional barriers or adding individual preferences as part of the decision logic. We have adopted a much simpler approach, described below. While not addressing all the criticisms of the approach, it does allow for the treatment of barriers and preferences without fundamentally affecting the underlying logic.

Market share can also be constrained by the ability of an industry to grow rapidly to meet increasing demands, e.g. the rapid growth of the natural gas combustion turbine market at the turn of this century. This type of growth constraint is captured in the electric sector market share algorithm but not captured elsewhere in SEDS. In the electric sector, if the standard "logit" market share for a new technology requires explosive growth for that technology, the market share is dampened through a second market share calculation wherein the growth rate is part of the utility function in the logit. Similarly, in the biofuels and hydrogen modules, there are explicit caps on the rate of growth from one year to the next.

SEDS Team Response

The simpler approach allows for "implicit costs" that affect the choice logic in a way that accounts for behavioral or institutional barriers and preferences shown by consumers and businesses. Implicit costs can be added to the decision logic to mimic the choices made, either as a result of behavioral or institutional barriers or to reflect the underlying preferences that would either accelerate or retard the adoption of new technologies (these implicit costs can be negative). If we can bring evidence to bear about the effect of barriers or the effect of preferences on choice of technology, we can mimic these by adding or subtracting the implicit costs, which is simpler than altering the structure of the decision logic.

The SEDS market share algorithm for the electric sector is also being modified to represent better the transmission and integration issues associated with wind and solar (see Section 2.2.9). Also, a generic market share algorithm adjustment applicable to all sectors will be made to consider rapid growth in the utility function associated with a new technology.

Difficulties with the Proposed Response

How to "bring evidence to bear" is key to the usefulness of this approach, but this is also challenging when codifying institutional or behavioral barriers or preferences. The normal strategy to replicating market choices can be by using known costs and manipulating two factors: the logit parameter that controls how much market share a cost advantage achieves and the costs themselves. By allowing for an implicit cost, one can take what evidence exists about the logit parameter as fact and alter the implicit costs to track the adoption of the technology.

Timeframe for Resolution

The mechanics of including implicit costs is already part of the structure of some SEDS modules and could easily be incorporated in other modules. In 2010, implicit costs and an adjustment for rapid market share growth will be considered and developed where appropriate for all modules. The timing of the reformulation of the electric sector market share logit for wind and solar is discussed below in Section 2.2.9.

2.1.3 Foresight (Short)

Reviewers' Recommendation

> The use of myopic expectations in every market is a serious flaw that needs to be corrected.

Model Development Context

There is limited foresight in some SEDS modules. For example, in the electric sector, expectations of future fuel prices are based on recent trends in those prices, expectations of future carbon allowance prices are a function of legislated future carbon emission reductions or carbon taxes, and expiration of tax credits with legislated sunset provisions is assumed. However, as a simulation model that moves forward through time, SEDS cannot provide perfect foresight on its endogenous variables without iteration over the time steps, which is prohibitive in terms of run times.

SEDS Team Response

We have not implemented a perfect foresight capability in SEDS for two reasons. The first is that doing so would require an iterative approach over time steps as noted above. The second, more important reason is that a lack of foresight better reflects reality for many parameters (e.g., fuel costs and technology improvements). Nonetheless, there are parameters in which imperfect foresight is warranted (e.g., anticipation of yet-to-be-legislated limits on greenhouse gas emissions). SEDS could tie expectations of such major market drivers to the inputs associated with the probability distributions for those uncertain drivers. In particular, impacts of possible future greenhouse gas regulation could be quantified and included in the market share calculations. For example, we could use risk adjusted discount and interest rates, as is currently done in NEMS, to capture investor and lender concerns regarding the possibility of future costs associated with carbon emissions.

If in a particular stochastic (or deterministic) trajectory through time, a carbon cap is implemented, then from that point forward investors within SEDS should be assumed to have some foresight as to the increasing cost of carbon allowances. We will develop an imperfect-foresight algorithm for this. Most likely, it will have a table of initial allowance prices determined from prior analyses by SEDS and other models as a function of ultimate reduction levels and time to that ultimate level. These initial prices can then be increased annually by the discount rate as in existing Hotelling approaches.

Difficulties with the Proposed Response

We will have to program each individual future uncertainty into SEDS. The alternative solution of using risk-adjusted discount and interest rates requires the estimation of those rates. The algorithm for foresight of carbon allowance prices under different cap levels will have to be robust.

Timeframe for Resolution

As of January 2010, SEDS has been modified to use risk-adjusted discount rates to capture many investor and lender uncertainties. By September 2010, we will address the future impacts of possible carbon legislation through inputs for possible future carbon allowance prices.

2.1.4 Common Metrics and a Decision-Theoretic Approach (Henrion)

Reviewers' Recommendation

> The model does not seem to have clear common metrics that can be used to compare technology impacts. Consider using net present value wherever possible for quantitative economic effects. The model needs a coherent decision-theoretic approach to compare R&D investments. The review team identifies this point as among the most important.

Model Development Context

The key metrics used to analyze SEDS results for portfolios of R&D projects include:

- Greenhouse gas emissions (e.g., in tons CO_2 equivalent per year or cumulative to selected forecast year)
- Energy cost (e.g., total dollars/year, or NPV[4] dollars to forecast year)
- Energy security, as oil imports (e.g., as barrels/year, or cumulative barrels to forecast year).

SEDS does use net present value as a way to combine a flow of costs over time.

SEDS Team Response

Decision analysis, which is the application of decision theory to real-world decision problems, provides a set of practical methods and tools. We have already adopted several of such methods and tools in the design of SEDS. Here, we list the key methods of decision analysis; how or whether they are addressed in SEDS; and proposed extensions, especially those that support a multi-attribute evaluation of portfolios.

Decision trees and influence diagrams are complementary representations of the qualitative structure of a decision problem. They identify decisions, chance variables and objectives, and the dependence or influences among them. We have not used decision trees, as they do not scale well for large models such as SEDS because of combinatorial explosion. SEDS was created as a hierarchy of influence diagrams, using Analytica's facilities for creating different types of variables and linking them with arrows to show influences.[5] The diagrams are organized as a hierarchy of modules so that each diagram is limited in scope and therefore more easily understood. . SEDS employs Analytica's extensions to the conventional influence diagram notation, including modules, nodes for indexes that identify dimensions of arrays, constants, and functions.

Expert elicitation: SEDS uses the results of the DOE Office of Energy Efficiency and Renewable Energy (EERE) risk analysis, a sister project to SEDS, which obtained expert

[4] Net present value.
[5] Analytica is the software on which SEDS runs.

opinions on the uncertain future performance of each technology in the form of probability distributions. See the Section 2.2.7 for details.

Representation and propagation of uncertainties: Each uncertain input is represented as a chance variable with probability distributions obtained from the expert elicitation. In many cases, these are multivariate distributions, represented as an array of distributions. SEDS uses Analytica's built-in Latin hypercube sampling to propagate the uncertainties through the model and estimate distributions on results from a random sample. This sampling method has computational complexity that is linear in the number of uncertain variables, and hence is tractable for such a large model with hundreds or thousands of uncertain variables—unlike standard decision tree methods with discrete distributions that would be intractable for a model this size.

Bayesian updating: At present, we see no need to employ Bayesian updating because we are not modeling the combination of new evidence with prior probability distributions.

Risk aversion: Some decision theorists have argued there is no need to represent risk aversion for most governmental or societal decisions because the size of impacts—even if in billions of dollars or thousands of lives—are small relative to an entire country's gross domestic product (GDP) or population. Others argue that decisions relating to global climate change, as addressed by SEDS, have such large potential effects that modeling risk aversion may be appropriate. Finally, inasmuch as SEDS tries to estimate private sector response to different scenarios, risk aversion by private sector decision makers can be important. To capture the latter, we will add a risk adjusted discount rate capability, as described in Section 2.1.3 above. In addition, the probability distribution outputs of the model allow the model user to estimate risks associated with different scenarios and policies.

Multi-attribute utility functions: SEDS was designed to focus on three major objectives or attributes to compare R&D portfolio results:

- Greenhouse gas emissions (e.g., tons CO_2 equivalent per year or cumulative to selected forecast year)
- Energy cost (e.g., dollars/year, or NPV dollars to forecast year)
- Energy security, as oil imports (e.g., barrels/year, or cumulative barrels to forecast year).

All three metrics may be combined over time using net present value with an appropriate discount rate. There are theoretical arguments about what discount rate to use for such decisions, especially for the non-cost objectives. For simplicity, we use the same discount rate for all three as selected by the end user.

Multi-attribute decision analysis offers techniques for developing scales for each objective and combining them into a single measure of utility to compare alternative outcomes. A simple approach would be to specify a dollar cost for greenhouse gas (GHG) emissions, perhaps as the amount that society deems appropriate to avoid each ton of CO_2 emissions—akin to a carbon tax. Similarly, we can place a social cost on oil imports in terms of dollars per barrel of oil imported as a proxy for the risks of dependence on foreign sources of oil. With these two conversion factors, we can use a simple additive function to combine the three attributes into a single measure of utility denoted in dollars. We will give users the ability to select these conversion values and to perform sensitivity analysis to see how varying values would affect the relative value of portfolios.

We recognize that these conversion values are unavoidably controversial. So, we will continue to offer the option of comparing portfolios and scenarios in terms of their scores on each of these three metrics without combining them. One approach to scoring that we will explore assesses the percentage increase or decrease on each attribute relative to a baseline scenario, which allows the attributes to be compared directly on a common scale.

Some will argue that the utility functions should be non-linear and perhaps non-additive in the attributes. Global GHG emissions will depend on how other countries change their GHG emissions, perhaps influenced to some degree by U.S. actions. GHG emissions are likely to affect climate, and climate changes affect humans, including their agriculture, health, and economies in ways that are dynamic and decidedly non-linear. Similarly, one might argue for non-linear social costs of oil imports. However, developing a model that could achieve a high degree of scientific consensus would be extremely challenging. We see this as beyond the scope of SEDS. Accordingly, we accept a simple linear additive multi-attribute model and offer easy sensitivity analysis to the two weighting parameters (cost per ton of GHG emissions and cost per barrel of imported oil).[6]

Portfolio analysis: Decision analysts have developed a variety of techniques to assist in the evaluation and optimization of R&D portfolios. SEDS was designed specifically to analyze and compare portfolios. Currently, it lets the user design a portfolio by selecting base, target, or "overtarget" levels for each technology or for an entire EERE R&D program comprising a group of technologies. We have recently extended SEDS to analyze funding levels that are between any two of these three points. Even with three funding levels per technology and about 40 technologies, there are about 3^{40} possible portfolios. A straightforward approach to simplify this is to define a base scenario (e.g., baseline funding for every technology or "target" funding for every technology) and then examine the effect of modifying the funding level for each program or each technology to the other two levels, while holding all the other programs or technologies at their base level. This creates 2n+1 portfolios—where n is the number of programs (or technologies)—a more tractable number.

Given a multi-attribute utility function, it might be possible to perform optimization to find the best portfolio according to that function subject to a constraint on the total R&D budget using one of the nonlinear optimization engines available in Analytica. Because of the complex interactions among the technologies in their joint effect on utility and the

[6] We may also offer natural gas imports as an attribute to be considered in a combined metric.

high-dimensionality of the search space, this may be a nontrivial optimization challenge. Consequently we do not plan to investigate this in the near future.

At the cost of additional complexity, it would be possible to represent this as a dynamic programming problem with decisions on the portfolio to be made not just in the current year but also at one or more future points in time, provided earlier uncertainties are resolved. For example, if some technologies succeed at producing low-cost energy early on, there might be less need for R&D in competing technologies—and vice versa. We will explore the tractability of such dynamic optimization, starting with two decision points: the current year and one future time, perhaps 10 years hence.

Difficulties with the Proposed Response

Developing an additive multi-attribute utility function letting users easily modify the parameters, as proposed above, will be technically simple and will be implemented. The challenge for the user will be the controversial nature of the weights needed to combine the attributes. Because moving to a nonlinear function that treats risk aversion would add excessive complication and controversy, we propose not taking that step.

Defining what we mean by an "optimal" portfolio is very different from being able to compute an optimal portfolio given a criterion. Beyond the challenges of combining different metrics, issues of correlation between outputs are also important. We need to improve the expert elicitation process to get better information about correlation (or lack of) between different technical and market parameters. In summary, the optimal incremental use of R&D dollars amongst many choices to "optimize" a portfolio is nontrivial and depends on many factors.

Providing a simpler interface for manual definition and exploration of portfolios would be relatively straightforward. Indeed, much of the work is already done. Adding automated optimization may be computationally challenging, especially for dynamic programming, and will require some experimentation and perhaps alternative approaches to creating a more tractable approximation.

Timeframe for Resolution

By April 2010, we plan to add a simple linear multi-attribute utility model for comparing portfolios and scenarios. We will include algorithms and displays to compare changes to EERE programs and technologies one at a time, while holding all other programs or technologies at their defined base level. We will also add displays that show the three attributes scores as percentage changes from a baseline scenario without combining them.

By December 2010, we will explore the addition of a two-stage dynamic programming approach.

2.1.5 Technology Cost Data (Henrion & Jenkin)

Reviewers' Recommendation

> Needs better underlying data on technology and supply chain cost info (e.g., biomass technology has complex costs, some gaps in cost info).
>
> Based on preliminary results, the technology costs may not be realistic – recommend expanding sources, e.g. EPRI, IEA. The review team identifies this point as among the most important.

Model Development Context

In most cases, the technology costs have been carefully estimated as probability distributions on key technology performance metrics by a number of representative experts, using the expert elicitation described in Section 2.2.7. However, the expert elicitation has not been applied to areas where DOE does not have R&D programs, such as biomass production. In this case, SEDS used deterministic biomass supply curves that change over time and are similar to those used in NEMS.

SEDS Team Response

Certainly, there is scope to improve the representation of technology costs could be improved, including biomass supply and other technologies where the size of the resource base is an important variable (e.g., geothermal). This will be an important focus going forward. For biomass, we hope to use a simplified version of supply curves generated by the Biomass Scenario Model (BSM) under development at NREL, perhaps with new data generated from PolySys. We hope to develop risk assessments to quantify the uncertainty in these models. We will also seek other sources of available information on technology costs in general, including the Electric Power Research Institute (EPRI) and the International Energy Agency (IEA).

Difficulties with the Proposed Response

The practicality of developing better models of supply information depends on the cooperation of the program teams developing these supply models, e.g. the biomass program team. The practicality of performing expert elicitations depends on the availability of resources to support risk analysts, recruit experts, and conduct the elicitations.

Timeframe for Resolution

We aim to redo the biomass supply curve and conduct a risk analysis to express the uncertainty explicitly. We hope to perform a full expert elicitation on key parameters for the biomass supply curve (e.g., energy crop yields, area potentially available for cultivation, costs for agriculture, harvesting, and transportation). But, if there are insufficient resources, we will use a simplified approach based on limited interviews with a few experts. The time frame will depend to a major degree on the availability of support and cooperation, but we hope to complete the biomass supply curve by June 2010. We will examine other databases for conventional technology costs by February 2010.

2.2 Responses to Other Issues Identified by Reviewers

2.2.1 Connections to other Models/Validation (Short)

Reviewers' Recommendation

> (The reviewers) suggest that a selected set of SEDS analyses designed to address known, existing analyses by other models be done. The results will allow a thorough characterization of capabilities and limitations. Look to macroeconomic analyses done as part of US Climate Science Program, IPCC, and others.
>
> The SEDS modeling team should formalize relationships with other modeling teams (CIMS, NEMS, MARS, etc). Some parts of these modules could feed information into SEDS to reduce development time and cost.
>
> Validation of the model is important to consider

Model Development Context

SEDS results have been compared to those of the Energy Information Administration's NEMS model for the Annual Energy Outlook 2009 (AEO2009) reference case.[7] This exercise focused on calibrating the results for the first year modeled (to ensure proper inputs and complete coverage of the energy sector). For subsequent years modeled, the emphasis was on identifying the differences in results, understanding them, and modifying SEDS where necessary. In general, SEDS results were not calibrated to NEMS results as there were intentional assumptions and inputs that caused many of the differences. No direct comparisons have been made with other models such as those that are part of the U.S. Global Change Research Program, Intergovernmental Panel on Climate Change (IPCC), or others.

SEDS is connected in a number of ways with other models. In particular, the models mentioned by the reviewers—CIMS, NEMS, MARS[8]—are each actually operated by SEDS team members. Joe Roop of Pacific Northwest National Laboratory (PNNL), who led the development of the SEDS industrial sector module, is the leading U.S. user of the CIMS model. Frances Wood of OnLocation, Inc./Energy Systems Consulting, who conceptualized the SEDS hydrogen module, is probably the leading user and developer outside of the Energy Information Administration (EIA) for the NEMS model. Don Hanson, who led the development of the SEDS refinery model with input from John Marano from the MARS model, is a frequent user and supporter of MARS. In addition, SEDS draws from NREL's Regional Energy Deployment System Model (ReEDS) for the post-busbar supply curve costs for wind energy. And, the SEDS buildings modules built by Chris Marnay and others at Lawrence Berkeley National Laboratory (LBNL) are based on concepts developed previously by their team for the Distributed Energy Resources Customer Adoption Model (DER_CAM).

[7] Unfortunately, this was not presented at the May 2009 review.
[8] Macro Analysis of Refining Systems (MARS) Model

SEDS Team Response

The SEDS team will document the existing comparison with the April AEO2009 ARRA[9] reference case (or AEO2010 Reference Case should it become available in time) and post it on the SEDS Wiki Web site[10] by 2010. By July 2010, we will also compare [SEDS] with the recently completed NEMS-based EIA analysis of the Waxman-Markey Bill (the American Clean Energy and Security Act of 2009) to examine how these two models perform in extreme (albeit increasingly likely) scenarios.

The SEDS development team agrees that model validation is important. Validation can take many forms. The SEDS team has run extensive sensitivities deterministically under extreme scenarios to identify response issues. We will document these on the SEDS Web site. As mentioned above, we have also conducted comparisons with results from other models.

Difficulties with the Proposed Response

Comparisons with results from other models are confounded by the many degrees of freedom possible in such comparisons. These include:

- Which scenarios to compare
- What outputs to compare
- What spatial level to compare (e.g., nationally versus regionally)
- What point in time to make the comparison (e.g., the last year simulated by the model with the shortest horizon?)
- What constitutes an acceptable level of similarity for an individual parameter
- What constitutes an acceptable level of similarity across all the parameters compared
- Which model or models are in error.

We have planned a formal comparison to NEMS as it is widely accepted as the "currency" of U.S. energy policy debates. In other words, it is almost incumbent on other models to explain how they differ from NEMS. However, if we focus too much on differences with NEMS or any established model, we risk limiting the insights possible from SEDS. In retrospect, we believe the differences between major forecasts have often been much less than the gaps between "the herd" and the evolving history.

Timeframe for Resolution

We will conduct a second comparison with the EIA's Annual Energy Outlook, either AEO2009 or AEO 2010 (depending on availability of all AEO2010 results) by April of 2010. At the time of the posting of this document, we have already improved SEDS' ability to respond to carbon caps and posted on the SEDS Wiki a comparison of SEDS results with the recently completed EIA NEMS analysis of the Waxman-Markey Bill.

[9] American Recovery and Reinvestment Act of 2009
[10] https://seds.nrel.gov/

2.2.2 R&D Focus on User-Interface Screen (Milford)

Reviewers' Recommendation

> The first input screens seem too policy focused, given that the model is intended to help DOE managers with R&D investment decisions. Screens on R&D funding should be up front.

Model Development Context

As of the May 2009 review meeting, little focus had been placed on the SEDS user interface. The interface was designed merely to illustrate how a user might change settings and view results. And, because the model has not undergone much outsider testing, the interface has not been finely tuned by user suggestions.

SEDS Team Response

The reviewers' recommendation would improve the original user interface. On the first input screens, we will provide users with the abilities to input R&D improvements and adjust settings.

Difficulties with the Proposed Response

There are no mechanical difficulties with this approach. As with other recommended changes, it is difficult to balance competing requirements that include easy access to many input and output variables; a user-friendly interface for novice end users; and comprehensible tables and graphs with a reasonable number of dimensions.

Timeframe for Resolution

We have already begun highlighting the R&D portfolio options and analysis results on the main SEDS screen. We have created an input table with choices of the R&D program level of funding for each program, and, in more detail, for each technology in each program. We are also adding results based on an automated analysis that runs the model, changing the funding level of each program while holding the other programs at a base level. We will continue to emphasize R&D portfolio options during further refinement of the main screen and relegate some aspects of lesser importance to sub-windows.

2.2.3 Regionality (Marnay)

Reviewers' Recommendation

> The model should be regional if serious policy analysis and technology assessment applications are contemplated…. This is a tool for R&D planners, not for policy analysts

Model Development Context

This choice of regional structure arises self-evidently in the development of any energy policy model. Because SEDS is designed primarily for national policy makers, the need for regional results is minimal. In the early stages of SEDS development, the SEDS team deliberately minimized computer run-time and maximized module consistency by developing a national model, while in a few cases we created the structure necessary to subsequently add regional detail. SEDS developers have always intended to add regionality where it is appropriate, corresponding data are available, and module inconsistency is not too burdensome.

SEDS Team Response

While regional detail is critical to some aspects of a national energy model, it may be of marginal benefit elsewhere, and added detail always comes at some cost. In addition, data limitations often dictate the level of model detail or impose inconsistent levels among its various parts. Given that (1) the primary objective of SEDS is to represent the uncertainty in long-term forecasts and (2) the benefits of regionality are uneven and not easily captured, postponing this issue to the next generation was a reasonable choice. Indeed, other models that have been used effectively for policy and or Government Performance Results Act of 1993 (GPRA) analysis have operated at the national level (e.g., MARKAL until quite recently). Further, since the addition of regional detail can create inconsistency between modules (a major problem with NEMS), the SEDS team is wary of creating another opaque energy model. That said, regional variation is certainly vital to some aspects of an energy model (e.g., regional climate effects on building energy usage patterns).

The SEDS team will introduce more regional detail in future versions. In the case of the buildings module, the structure for a regional representation by census region is in place. For the electric sector, we will separate new generation requirements into those that can be met with a full mix of technologies and those for which coal is not an option (e.g., California). For the transportation sector, we will consider distinguishing between urban and rural transport.

Difficulties with the Proposed Response

Despite the obvious desirability of increased regional granularity, the challenges listed above must still be addressed. There are two additional challenges to note. First, evaluating the benefits of regionality is a little more difficult than some other potential model enhancements because it involves a structural change to the model and not a simple change in a single variable whose influence can be gauged by a tornado diagram. Second, the added complexity of a much-expanded data set can impose constraints on the model. For example, when a regional breakdown of certain national numbers is not allowed to change over time, the model is over-constrained.

Timeframe for Resolution

We will add regionality to the buildings module by September 2010. Similarly, we will break out the coal-restricted areas in the electric sector, and we will distinguish between urban and rural transport in the transport sector in 2010.

2.2.4 More Technologies (Marnay)

Reviewers' Recommendation

> Quantitative analysis of R&D choices is highly challenging as it requires an evaluation of the likely success of R&D dollars and the impact of those

> successes against a future that will depend on how all technologies advance.

Ergo more technologies need to be added to SEDS including synergisms between all technologies.

Model Development Context

Inevitably SEDS is patchwork and piecemeal in its treatment of the myriad technologies that will shape our energy future. The SEDS team chose to limit itself to a small set of pilot technologies and to treat them in some depth. In this way the full process, including the expert elicitation and details of over and under target budgets could be demonstrated. This approach does, however, result in a long lead-time before the full DOE portfolio of technologies can be evaluated.

SEDS Team Response

The reviewers are of course correct in saying that a model that does not fully represent the competition among all technologies cannot produce completely accurate results. But, all models are incomplete, and the challenge is to find an approach to adding technologies that delivers useful intermediate results. Deciding how to add the various technologies under development by DOE's many R&D programs is actually a significant challenge, and indeed many programs are not represented in detailed models such as NEMS. The SEDS team does not have a broad set of criteria for choosing additions, and one should be developed. The team will endeavor to choose future additions in such a way that main areas of competition are incorporated sooner rather than later.

Difficulties with the Proposed Response

While we can stop some of the biggest fish from escaping the net, many small ones will still be lost. In other words, the representation will always be incomplete. This problem can be can only be modestly attenuated.

Timeframe for Resolution

Achieving a full fleet of technologies will inevitably be a lengthy and ongoing process. As a first step, we will develop a set of criteria for technology inclusion by May 2010.

2.2.5 Interaction of Federal, Private, International R&D (Hanson)

Reviewers' Recommendation

> A critical consideration of federal R&D is how those expenditures fit within total R&D expenditures for energy research. Expenditures by foreign governments are important as are expenditures by private industry. The SEDS analysis framework does not address this issue very well... SEDS should go forward but one needs to recognize explicitly where some of the limits and biases might be and correct those through side analysis and use of other models or approaches." [J. Reilly].

The reviewer said that focusing the criteria on commercial payoff from DOE R&D might bias the allocation of funding toward applied R&D. The reviewer also pointed out that private sector and international R&D may not be exogenous; rather the level of this R&D should be expected to respond to SEDS model projections of energy prices and climate policy.

> On the question of R&D outside the walls of DOE: my understanding is that the expert panels are instructed to consider these sources of R&D for the baseline (no federal R&D) case, and that the distributions around the DOE goals for the 'with federal R&D case" are intended to measure the incremental gains from federal dollars. There is certainly the possibility that Federal R&D will crowd out private R&D, but there is also the possibility that federal R&D will stimulate deeper private R&D (as patent research has shown). [M. Leifman].

Model Development Context

This is a broad scope issue and hard to relate to modeling individual energy technology R&D goals and outcomes. The SEDS team has always recognized the importance of R&D in the private and international sectors. In the expert elicitation for technology cost and performance improvements, the experts were explicitly instructed to consider these outside R&D efforts when estimating the impacts of DOE programs.

SEDS Team Response

Private and foreign R&D affect benefits from federal R&D in both directions, and the end result may be a "wash." Higher energy prices would likely induce more of the other R&D effort but also increase the value of any incremental achievements from federal R&D.

Economists have found mixed results when surveying empirical work on this issue.[11] Crowding out is currently not a serious issue in the energy sector as less than $12 billion a year is spent on energy-related R&D worldwide. But, at a proposed $100 billion/year, a large international energy R&D program would constitute about 12% of current global R&D across all sectors. At that level, there would likely be some economic cost (opportunity cost) to this redeployment of scientific and engineering talent away from other productive ends. A growing supply of scientific and engineering talent provides one reason to expect crowding out effects that are quite low worldwide. In particular, rapid economic development in East Asia and South Asia provides one avenue for mediation of crowding out. This issue is generally well known, and some complementary policy steps are being pursued separately (i.e., emphasizing science and engineering education. Also, the federal government has had a policy to challenge other countries to match U.S. R&D expenditures).[12]

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[11] David, P. A., B. H. Hall, and A.A. Toole. (2000). "Is public R&D a complement or substitute for private R&D? A review of the econometric evidence." *Research Policy* 29(4-5): 497-529.
[12] Gregory Nemet (Professor, University of Wisconsin-Madison), personal communication.

Difficulties with the Proposed Response

In light of the complexity of the issue and its broader scope beyond DOE programs, little in the near term—beyond the current expert-provided cost and performance estimates that considered R&D efforts beyond DOE—could be added to SEDS.

Timeframe for Resolution

No further resolution is required

2.2.6 Life Cycle Impacts (Roop)

Reviewers' Recommendation

> Results would be improved by adding the capability to analyze and communicate life cycle impacts (e.g., land use change, manufacturing of materials that originate outside the US that are not in the industrial sector module such as batteries, investment in rail, road, pipeline, and electricity transmission infrastructure, fuel extraction and refining.

Model Development Context

The initial focus of SEDS is on the major energy end use sectors and the supply of energy to them. It is specifically designed to allow for estimates of the impact of DOE-developed technologies, so in its initial manifestation there is little emphasis on the items mentioned in the reviewers' recommendation.

SEDS Team Response

The SEDS team agrees that investment in energy infrastructure is a legitimate concern of the model and needs to be taken into account. Similarly, major changes to the infrastructure that affect energy use—changes in the way roads, rail, and pipelines are constructed or implemented—are also a legitimate concern, insofar as these changes affect energy use. SEDS could not reasonably handle some of the other items, such as land-use changes and non-domestic sources of materials, without a complete re-thinking of what the model is designed to do.

As with any life cycle impact study, the critical factor is where the boundary is drawn. While it may be true that an African butterfly's particular movement might give rise to an Atlantic hurricane, attributing that effect to the butterfly is extremely difficult if not impossible. We have drawn the boundaries in a way that we feel captures the major concerns when it comes to portfolio management in the DOE and EERE.

Difficulties with the Proposed Response

Inasmuch as the SEDS team does not feel substantial changes are needed, there should be no difficulties with this approach. One advantage of the approach is that it does not complicate the structure of the model and does not add detail that might obscure the major focus of the model.

Timeframe for Resolution

No further resolution is required

2.2.7 Expert Elicitations and Risk Evaluations (Henrion & Jenkin)

Reviewers' Recommendation

The review produced many comments and recommendations on how to do an expert elicitation and how to treat uncertainty using probability distributions. For greater clarity, we reproduce the detailed reviewers' recommendations below. After each recommendation, we provide our response.

Model Development Context

EERE conducted an extensive risk analysis project (the sister project to SEDS mentioned in Section 2.1.4) to elicit expert opinion on the future performance and cost of energy technologies.[13] This project, which addressed most of the key technology programs funded by EERE, has been led by DOE with assistance from some members of the SEDS team together with additional risk analysts and facilitators appointed for each program. The risk analysis team developed a detailed protocol for conducting the assessments based on best-practice recommendations for expert elicitation and designed to minimize biases, both cognitive and motivational.

The protocol included guidelines for each of these steps in performing the expert elicitation:

- Recruiting and training a risk analyst and facilitator for each program. The risk analyst manages the process. The facilitator assisted, with special attention to working with the experts.
- Recruiting and selecting experts
- Introducing and preparing the experts for the process
- Producing an "expert briefing" document that summarizes findings from key reports and other sources relevant to the technologies of interest
- Structuring the technologies and quantities for assessment
- Conducting the actual assessments
- Developing a spreadsheet template for recording the assessments
- Reviewing and revising results with experts where needed
- Aggregating risk assessments over the experts
- Formatting and delivering the resulting distributions for use by SEDS and others.

The risk analysis team conducted extensive pilot risk assessments in 2008 for most of the programs. In light of the pilot results, the team revised and expanded the assessment protocol and training process, and further assessments were conducted in the first half of 2009.

13 We did not describe this in detail at the May 2009 review because we wanted the focus to be on the SEDS model itself, which in retrospect may have been a mistake.

For each technology, the risk analysis team identified key technology performance metrics (TPMs), such as efficiency, unit capital cost, operating and maintenance cost, and capacity factor. Team members recruited experts from industry, academe, and national labs to assess their uncertain opinions about these TPMs in the form of probability distributions. In most cases, the experts assessed TPMs for two goal years (e.g., 2015 and 2025) that varied by program. The assessed distributions were conditional on three levels of R&D program: target program, assuming continued DOE funding at the current planned level; base program, meaning without DOE funding but with ongoing R&D funding by US industry and international stakeholders; and an overtarget program, doubling the funding from the target program.

For more details, such as the elicitation training presentation (developed by Max Henrion) or the results from the Solar Energy Technologies Program elicitation (developed by Jim McVeigh), please contact Thomas Jenkin or Max Henrion.

SEDS Team Response

The expert elicitation process outlined above is a sister project to SEDS development rather than an intrinsic part of SEDS. Accordingly and because of the limited time available in the May 2009 review meeting, we did not present the details of the risk assessment process. Perhaps, this was a mistake given the central role of the elicited distributions to the credibility of SEDS. In any case, we regret not spending time to make the expert elicitation clear to the reviewers.

Below we provide specific responses to each comment. Reviewers' comments are in block quotations (i.e., indented) to distinguish them from our response.

> Follow the established procedures and protocols of conducting peer-reviewed expert elicitations."

We agree. The expert elicitation tried to follow established procedures and protocols, as much as was practical and subject to resource limitations.

> Draw on experts from outside of DOE. … Ensure that the experts chosen to give input include a cross-section of those with knowledge of energy and related markets. Be sure that there are inputs not only from technology developers, but also from end users, etc.

We agree. Each program recruited experts from industry, academe, as well as DOE and national labs. For some programs, recruiting many experts from industry proved difficult to recruit mainly because of concerns about sharing proprietary data.

> Ensure that there are sufficient resources for the experts providing input.

Risk analysts provided introductory preparation to experts, and, in most cases, an "expert briefing" summarizing key evidence. Only a few programs were able to offer honoraria to experts for their time. We hope that additional resources will be available in the future.

> Expand the expert evaluation of R&D benefits and learning by doing assumptions.

In some cases, the expert briefing included a review of learning and improvement rates from past R&D. Few programs explicitly addressed learning-by-doing (LBD) after the last goal year. This is an area to be improved in the future.

> Experts are not expert at probabilities and projects. Provide training for the experts as well as those doing the elicitation, or continue providing training.

We trained the risk analysts and facilitators who conducted the elicitations, and we provided introductory material to explain the process to the experts. We plan to provide and possibly expand this training in future elicitations.

> Develop a plan for updating inputs from experts so they will stay engaged with the process. This needs more thought.

We agree. We plan to provide feedback to the experts on how their distributions impact the results from SEDS. In addition, it will be useful to track assessments over time and as results become available so that we can compare assessed distributions with actual values and provide this as feedback to the experts.

> For clarity, identify which distributions were developed through the independent expert process.

All inputs distributions on the effects of R&D on technology performance were obtained via expert elicitation. We will clearly indentify the few input distributions not obtained via expert elicitation.

> Characterize and summarize how the literature quantifies successful outcomes of past R&D investments,[14] in addition to taking expert opinions on future impact of R&D investments.

In some cases, the expert briefing documents summarized past improvements in technology performance that were due to R&D. This is an area worth expanding. It may be useful to characterize past learning rates in terms of percent improvement either per year or per doubling of cumulative capacity as a metric to facilitate comparisons of technologies at various levels of maturity.

> This model requires continued linkage to robust technical risk analysis and reliable determination of good bounds for other key lever inputs.

We agree.

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[14] Costa Samaras noted that Julia Lane at the National Science Foundation (NSF) is assembling such a study.

> To the extent possible, ensure level of optimism/pessimism of R&D assumptions and impacts (cost, performance, date of availability) are derived consistently.

We agree. Estimating the impact of R&D is very difficult. Experts have to imagine the world with and without U.S. government R&D. It is hard to know what R&D will be spent on and how such spending will interact over time with private sector spending in United States and the rest of the world.

> The study of past R&D investments, when available, should be the primary source of information for determining the impact of future R&D investments. The EU has sponsored a long-term study on "learning through R&D" (SAPIENT) and the program offices should make every effort to acquire the details of that study and possibly use the lessons learned.

We agree. We will review SAPIENT findings.[15]

> The distributions and parameters chosen to represent stochastic variables are themselves uncertain and will influence the model result. Every analysis performed with this approach should carefully state this caveat since the selection of the distributions and their parameters could imply the model contains more information than it really has.

We agree. Most expert elicitations used a four-parameter distribution with a probability of advancement (probability that the technology improves relative to base value), mode, and 10^{th} and 90^{th} percentiles. We fitted a triangular distribution to the last three parameters. We judged this type of distribution an appropriate balance between simplicity and effort. Sensitivity analysis generally shows that the width of the distribution, subject to the expert's over- or under-confidence, affect the results more than the choice of the shape of the distribution (e.g., normal instead of triangular). We propose to carry out further sensitivity analysis on this question. We should also point out that the inputs to SEDS are distributions aggregated over experts using a weighted sampling process. These aggregate distributions are not triangular and are sometimes multimodal.

> There appears to be no real reason to believe that one type of distribution with specific parameters is better at representing the true underlying distribution than another. … One can only know the true underlying distribution by sampling from a revealed distribution about the past for the specific activities.

The goal of the expert elicitation is to obtain probability distributions that best represent the carefully considered uncertain opinions of each expert. In this sense, there is no "true" underlying distribution. We agree it would be insightful to examine the distribution of prediction errors in past projections for years for which we now know actual values (e.g.,

[15] Systems Analysis for Progress and Innovation in Energy Technologies

using EIA's retrospective review of past energy outlooks).[16] However, these error distributions, which are based on the single-valued estimates and modeling methods used for AEO, are only indirectly relevant to the expert elicitations and SEDS model used here.

> (We all recognize that random sampling from most distributions (with a few exceptions like Cauchy) will ultimately approach some normal distribution, as the sample grows infinite in size.)

SEDS uses a Monte Carlo (or Latin hypercube sampling) process to estimate probability distributions induced on the result variables by the probability distributions obtained from expert elicitation. The shape of the resulting distributions should not vary significantly with sample size, provided the sample size is adequate, and will not approach normality unless that is the shape of the underlying distribution. However, the error in estimates of specific parameters of the result distribution, such as their mean or 10th percentile, will approach a normal distribution with reduced error with increasing sample size.

Summary of Response
We agree on the importance of both conducting the expert elicitations using the best-practice methods and taking care on the selection of distribution shapes and parameters. There is always room for improvement, and we anticipate that the risk analysis team will continue to learn from each successive set of elicitations as well as from the thoughtful comments of the reviewers.

So far, we have focused on the elicitation of technical risk and uncertainty distributions. Further analysis is needed to produce both better estimates of market risk related factors; correlation of various technological outcomes; and understating of how these technological outcomes in turn may be related to market outcomes.

Expert Elicitation and Single-Point Estimates
We should point out that most critiques of the expert elicitation process apply equally to more conventional single-valued expert estimates used in non-probabilistic models. The challenges of selecting a panel of representative experts and minimizing their biases, both cognitive and motivational, cannot be avoided no matter which approach one chooses. There is a more substantial literature for expert elicitation of probability distribution than there is for single-value estimation. There are also more experience-based, best-practice guidelines for the latter than there are for the former. The most obvious difference is that the expert elicitation process for probability distributions enables the experts to be explicit about their uncertainty—how much or little they believe they know—information that is missing from conventional single-value estimates.

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[16] Energy Information Administration (2008). Annual Energy Outlook Retrospective Review: Evaluation of Projections in Past Editions (1982-2008). DOE/EIA-06403(2008). Washington, DC: Energy Information Administration.

Difficulties with the Proposed Response

The main difficulties with the proposed response are obtaining the resources, experienced staff, and funds to conduct expert elicitations with the desired degree of thoroughness and detail, and that are appropriate given the level of funds and outcomes at stake. Any elicitation process (like any modeling activity) must strike a balance between level of detail and level of effort for both analysts and experts.

The scale of this expert elicitation project is massive with about 40 technologies assessed to date, each usually having about 24,000 assessed numbers, including:

- Four or five technology performance metrics
- Three program levels (base, target, overtarget)
- Two goal years
- Four parameters per distribution (probability of advancement, mode, 10^{th} and 90^{th} percentiles)
- Five to nine experts per technology.

Timeframe for Resolution

DOE's risk analysis effort is expected to develop an updated "lessons learned" document by January 2010 that includes proposed improvements to the elicitation protocol for future assessments. By July 2010, the SEDS team will develop a set of sensitivities on the width and shape of the input distributions.

2.2.8 Limit Non-Modelers Change Options (Max Henrion)

Reviewers' Recommendation (Paraphrased)

Initially at least, the model should be released with either limited functionality or limited options for user manipulation. Either non-modelers should not be able to change parameters unrealistically, or some assumptions should be fixed.

Model Development Context

SEDS users with the free Player edition of Analytica can change only variables and options designated as inputs, but users with other editions can change any variable or formula.

SEDS Team Response

With Analytica Enterprise, we can save SEDS in a form that is locked as "browse only." This means that users with any edition of Analytica can only change designated input variables. Before saving SEDS in this locked form, we will review all current inputs and select as a subset those that are appropriate for end users to modify. We will also add "sanity checks" to prevent users from using unrealistic values or combinations of values.

Difficulties with the Proposed Response

Specifying range checks on all key inputs and input combinations may be time-consuming and will require careful judgment.

Timeframe for Resolution

We already have the capability to release a browse-only version of SEDS. When a public version is initially released, it will be a "browse only" version. We will release additional versions with further internal "sanity" checks over time.

2.2.9 RE Non-Dispatchability Costs as a Function of Load Met (Short)

Reviewers' Recommendation

> The model should ensure that more subtle aspects of technology costs are properly accommodated, such as the relative non-dispatchability of some RE sources. An example would be to indicate one cost if wind and solar are 20% of total electricity, or a different cost if they constitute 40% of total electricity.

Model Development Context

As of the May 2009 review, the SEDS model contained a supply curve for wind energy that presents the post-busbar cost of wind[17] as a function of the amount of wind capacity installed nationwide. This curve was developed in 2004 using the ReEDS model (then called WinDS).

In the SEDS buildings modules, a function curtails distributed photovoltaics (PV) output as PV generates a higher fraction of the load. The buildings module looks at the amount of PV being installed in the power sector and limits PV adoption in buildings if a ceiling on installed capacity is approached. This ceiling is currently based on the baseload-peak differential, but it could be based on other drivers.

These existing supply curves for wind energy and limits for solar energy use in SEDS were not discussed during the review because of time limitations.

SEDS Team Response

The SEDS team agrees the post-busbar cost of wind is a function of many factors, the principal ones probably being (1) the total amount of wind installed (mostly because of lower quality wind resources being installed farther from load centers) and (2) the fraction of load met by wind (because of higher system integration costs with higher wind energy fractions).

NREL has begun work on a new market share formulation for wind that will explicitly consider not only the fraction of load met by wind energy but also other factors driving wind utility in the marketplace. This new market share formulation will be based on runs from NREL's ReEDS, a much more detailed electric sector capacity expansion model. If this new market share formulation is successful, we will expand it to solar energy in SEDS.

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[17] In other words, wind incurs costs for transmission and system integration that are beyond its direct levelized cost of energy.

Difficulties with the Proposed Response

The development of the proposed new market share algorithm for wind energy is essentially the development of a reduced-form model based on outputs from the ReEDS model. How well it captures the ReEDS results over a wide range of scenarios remains to be seen. Even if this new algorithm successfully estimates market share, there will remain a need to capture total cost associated with the market penetration (e.g., wind integration and transmission costs, storage costs, and other costs) for the purpose of calculating electricity price within ReEDS. This will require further reduced-form modeling, but at least the market share algorithm itself will be more directly estimated.

Timeframe for Resolution

The implementation of the reduced-form market share algorithm in SEDS should be relatively straightforward. The more difficult task of developing the reduced-form algorithm will depend on the funding and successful completion of the ReEDS' team effort. We hope an initial version will be completed for wind energy by April 2010.

2.2.10 Comparing Cases or Scenarios (Henrion)

Reviewers' Recommendation (Paraphrased)

The model should make it easy to compare various cases.

Model Development Context

SEDS has a simple method for defining a case (or *scenario*) whereby users can select options and values for many key inputs such as whether there is a carbon cap or tax, whether nuclear power will be expanded, and what the global price of oil is. Users can compute and store results for each scenario, whether it is deterministic or probabilistic, and for subsequent comparison with other scenarios, such as a base scenario.

SEDS Team Response

We have been developing an expanded scenario management tool within SEDS that is designed to allow:

- Easier selection of options to define a scenario
- Easier addition of an input option or variable value as part of a scenario definition
- Automatic recording of the values of the options to make it clear which assumptions underlie each scenario
- Automatic computation and saving of results from a set of scenarios so that the user can set up a series of scenario runs and let the computer run them in sequence because it may take a long time to compute if there are many scenarios with large sample sizes
- Easier selection of scenarios to compare (possibly retrieving them from saved files) and easier display of comparison tables or graphs

Difficulties with the Proposed Response

There are no specific difficulties to report. However, building a system capable of handling all possible needs for comparing cases or scenarios is always difficult.

Timeframe for Resolution
While an initial cut at the case-comparison capability exists at the end of 2009, a robust capability will be prepared by April, 2010.

2.2.11 Outputs: Stochastic Results (Henrion)

Reviewers' Recommendation (Paraphrased)
The outputs need more attention to graphic design to show properly the stochastic results.

Model Development Context
Analytica offers a wide choice of methods to display probability distributions. These are immediately available from a pull-down menu on each graph or table showing an uncertain quantity, including:

- Mean value
- Statistics: Mean, median, standard deviation, minimum, maximum, and others
- Fractiles: Selected fractiles, such as the 5, 25, 50, 75, 95th percentiles
- Probability density function: Displayed as a curve or histogram
- Cumulative probability function
- Underlying sample values.

SEDS authors select an initial default view for each result. End users can then choose any other views that suit their preference. Current default results include probability density functions and fractiles (percentiles). Fractiles work well to show uncertainty in a quantity as it changes over time or another dimension.

SEDS Team Response
We agree that the selection and design of graphs and charts to display SEDS results are crucial. And, the review has highlighted the need to define and select result displays that provide better summaries and insights particularly in the representation of uncertainty.

At present SEDS can generate hundreds of output graphs and charts as default views of each output, and an end user can easily create more. What we need to do is to identify a small number of carefully designed results that provide the most insightful summaries for those with limited time and to do so in a user-friendly manner. We plan to explore additional views and displays as outlined below. We expect this exploration to reveal feedback from sample audiences and end users that will help to identify the displays that are most useful to common SEDS users. Of course, users who have particular interests and the time to explore will always be able to find or generate their own results.

The rich array of ways to display uncertainties may be overwhelming to many users. We suspect (and have found from initial feedback) that many users prefer a simple representation showing a few percentiles (e.g., 5th, 25th, 50th, 75th, 90th percentiles) as shown in Figure 1.

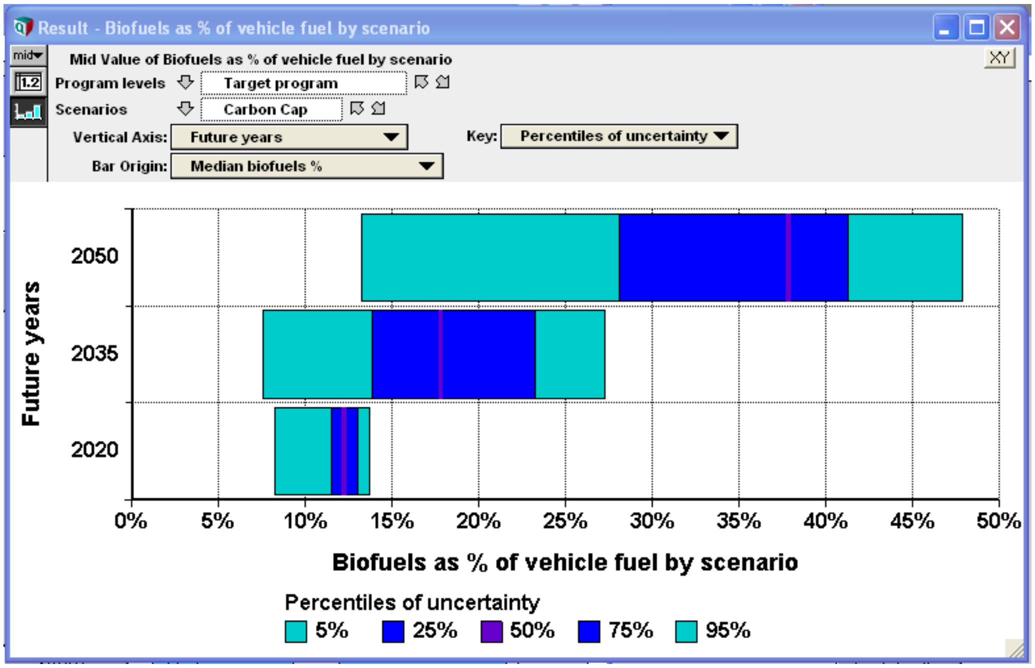

Figure 1. Example of result display: Selected percentiles for biofuels consumption as a percentage of total vehicle fuel consumption by energy for three forecast years

Similarly, while some users prefer to see quantities varying over time, such as prices or energy produced by type, it is often helpful to show results for two or three selected forecast dates as shown above. This format also works well to compare different programs or scenarios. See, for example, Figure 2.

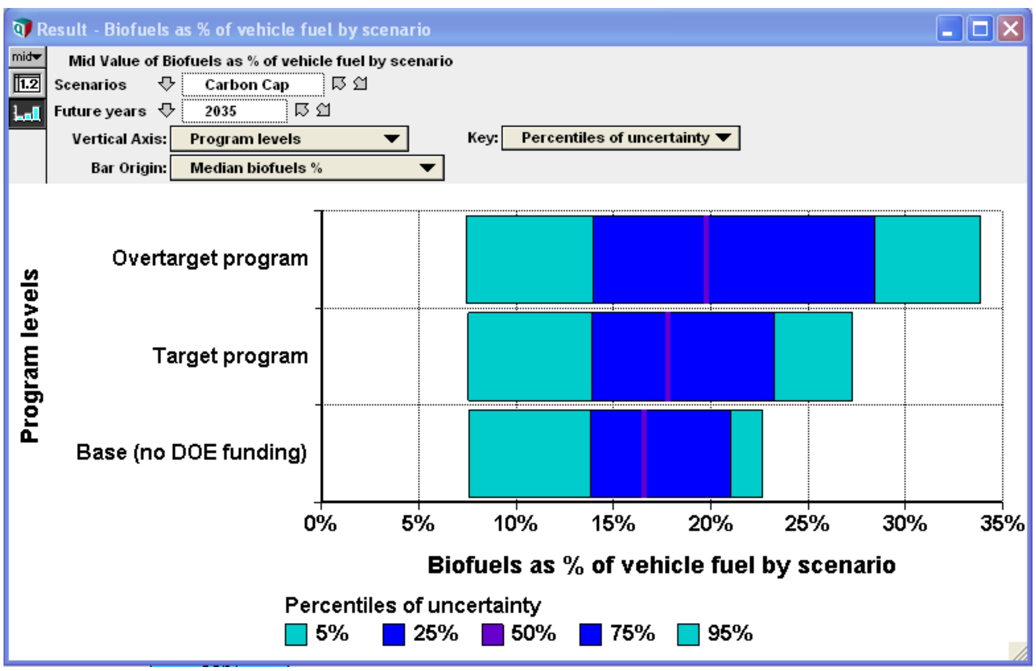

Figure 2. Example of result display: Percentiles of biofuels as percentage of total vehicle energy consumption for three program levels

The choice of method to display uncertainty depends on the specific interests and needs of the user. We propose to provide simple displays as the default views. Users that are more sophisticated can use Analytica's built-in options to select other views to meet their preferences.

Difficulties with the Proposed Response

The biggest challenge with the proposed response is to find ways to display SEDS results that are intuitive, do not overwhelm the use, and communicate the diversity and multiple-dimensions of the results that SEDS can generate, including uncertainties. This in part involves understanding clearly what results are potentially valuable (e.g., showing the impact of increasing R&D on likelihood of achieving specific carbon reductions). Analytica itself offers considerable, but not unlimited flexibility in graphing styles and options. In some cases, we copy results from SEDS into Excel to use additional graphing options. However, how to choose and create graphs must be more clearly known to potential users. A user guide showing a few useful figures and explaining how to create them seems appropriate. The degree of automation also needs to be considered, especially to ensure that valuable information is displayed for the specific cases shown.

Timeframe for Resolution

Designing and selecting clear displays for key results is a high priority for the SEDS team, and we have made major improvements as of the end of 2009. But, we expect to continue to develop and test new displays over time so we can find out what forms of display best meet the varied needs and interests of SEDS users.

2.2.12 Outputs: Synergies, Interactions, and Sensitivities (Henrion)

Reviewers' Recommendation (Paraphrased)

Consider developing ways to assist users in seeing synergies, interactions, and sensitivities among technology programs within the DOE portfolio. Users should be able to see the contributions of individual technologies to outcomes (e.g., CO_2 reductions).

Model Development Context

Building on features of Analytica, SEDS offers a variety of ways to compute and display sensitivity analyses, including:

- **Scenario analysis**: The user can select a set of input values and generate results to be compared against a base case or other scenario (see Section 2.2.10).
- **Parametric analysis**: The user can select a single important exogenous parameter, such as the global price of oil, and compare results for a series of values of the parameter from low to high. Many input assumptions are set as choice variables where you can set a particular value, both values, or all values to examine the effects on result.
- **Range sensitivity**: The user can examine sensitivity over a range by changing each uncertain input from a low to high value while keeping all other uncertain parameters at a mid value.

- **Elasticity**: The user can elect to show the elasticity, or the percent change of a result from a 1% change to each uncertain input.
- **Importance analysis**: The user can use importance analysis to conduct rank correlation of an output Monte Carlo sample to each probabilistic input.

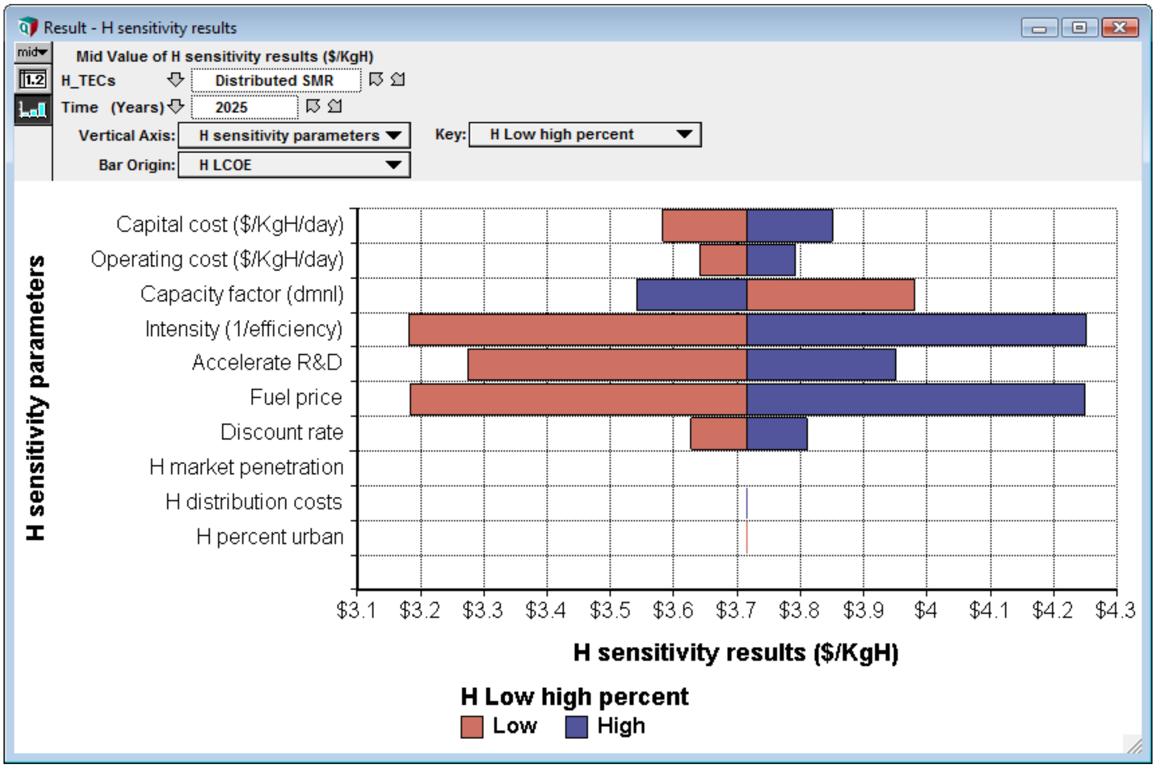

Figure 3. Example of range sensitivity analysis: Figure shows the effect on the levelized cost of energy (LCOE) of producing hydrogen from distributed SMR (steam methane reformation) of changing selected input variables from a low to high (10^{th} to 90^{th} percentiles for probabilistic variables) while holding all other inputs at their mid values

Analytica's Intelligent Arrays feature make it relatively easy to combine several of these measures of sensitivity—for example, to perform range sensitivity analysis or importance analysis for several scenarios, or to perform range parametric analysis and sensitivity analysis to explore interactive effects of parameters.

Because SEDS is so large, with so many uncertain parameters, performing a sensitivity analysis of a model result to all parameters at the same time is overwhelming. And, the results are difficult to digest. So, we have designed SEDS to perform sensitivity analysis hierarchically; for each module, it offers range-sensitivity analysis of the uncertain parameters within that module to the results of that module (e.g., the levelized cost of energy). At a higher level, SEDS can perform sensitivity analysis of the effect of levelized cost of energy from each technology to the overall results from the model (e.g., GHG emissions, energy expenditures, and oil imports).

One important type of analysis is to compare portfolios, where we show the effect of increasing or decreasing funding of individual technologies or programs on key results (changing GHG emissions, energy cost, oil imports), while keeping the remaining portfolio at the same level (base or target). In this way, we can isolate the effect of individual technologies on results.

SEDS Team Response

We will continue to develop and test new and clearer ways to analyze and display sensitivities, as well as ways to show the uncertain contribution of each technology to each result metric (GHG emissions, energy cost, and oil imports). We will also experiment with methods to identify synergies and interactions among parameters and technologies by using two-way sensitivity analysis, range-sensitivity analysis, and importance analysis. The user interface also needs to be improved to better allow analysis of "what if" R&D funding levels.

Difficulties with the Proposed Response

As with other expansions in analysis, it is hard to maintain a balance of richness of analysis without overwhelming users with the complexity and number of available displays.

Timeframe for Resolution

As of the end of 2009, we have developed an expanded range of types of sensitivity analysis, including further interactions combined with scenario analysis. We will obtain feedback from selected users to identify and highlight those that they find most valuable.

2.2.13 Explaining R&D and LBD Curves (Henrion)

Reviewers' Recommendation (Paraphrased)

A fundamental communications issue with the current approach is that the basis of the R&D and LBD curves from experts will be hard to explain in a concise manner. Thus, understanding what drives the results will be complex to communicate. This issue has to be addressed or SEDS will constantly be crippled by misinterpretations.

Model Development Context

We have already conducted range sensitivity analyses to show how future changes in technology performance metrics assessed in the expert elicitation (e.g., unit capital cost and conversion efficiency) and other parameters (e.g., discount rates and fuel costs) affect the levelized cost of energy (LCOE) over time for each technology. These provide a concise explanation of the relative importance of these parameters.

SEDS Team Response

We recognize the importance of communicating SEDS to show the R&D and LBD, as well as explaining how these learning curves are affected by key input parameters, and how they, in turn, affect the model results. We plan to further refine these displays in several ways, especially in hierarchical methods of sensitivity analysis, to identify the most critical parameters.

We will display the learning curves for each technology in terms of the change in LCOE over time. One form of analysis we will explore is to show tables and graphs of learning rates (i.e., percent reduction in cost per year or per doubling of installed capacity). This provides a relatively compact view of the results of the expert elicitations that enables comparison across technologies as they all use the same units (i.e., %/year or %/capacity doubling).

We will explore a further range sensitivity (or importance) analysis to examine the relative effect of the uncertain learning rate for each parameter assessed in the expert elicitation on the learning rate for the LCOE for each technology.

As for other displays, we will obtain feedback from users to find which of various displays communicate most effectively.

Difficulties with the Proposed Response

The biggest challenge here, as with other areas, is to provide clear graphs that show the important results, without overwhelming users with complexity or number of dimensions.

Timeframe for Resolution

We will develop result tables and graphs to compare learning rates across technologies by May 2010. We will refine range sensitivity analyses of LCOE of each technology by May 2010 to show the effects of the parameters assessed by the experts on these learning rates.

2.2.14 Global Energy Markets (Short)

Reviewers' Recommendation

> A global model would be superior to the current U.S.-only model since many energy and commodity markets are global. However, the reviewers acknowledge the run-time problems that a model like this might engender.
>
> Energy markets are all global markets. If SEDS tries to only capture the US marketplace, it will surely be completely inaccurate. There needs to be some way to represent global energy markets.

Model Development Context

The SEDS team has made provisions for the global nature of many energy markets. In particular, we developed a world oil module that simulates the impact of U.S. demand on both world oil markets and the price of imported crude oil. The gas supply module in SEDS also recognizes the potential for gas imports in the form of either liquefied natural gas (LNG) or a Canadian pipeline. Significant discussion has taken place throughout the development process on issues such as the import of bioethanol from Brazil and other countries.

SEDS Team Response

The SEDS team agrees that global energy markets have an important impact on U.S. energy markets. We believe the model has captured the more important global energy feedbacks and that the unique stochastic capabilities of SEDS allow modeling of the range of possible future international developments through probability distributions on energy import prices. Finally, the increase in run time that would accompany a full international model would be prohibitive. Thus, the modeling of global markets will be limited to refinements of the existing modules for oil, gas, and ethanol prices.

In Section 2.2.5 we address the separate issue of the impact of international R&D.

Difficulties with the Proposed Response

Inasmuch as the SEDS team does not feel any substantial changes are needed, there should be no difficulties with this approach. One advantage of the approach is that it does not increase the SEDS run time.

Timeframe for Resolution

No further resolution is required

2.2.15 Oil Prices (Short)

Reviewers' Recommendation

> A simpler oil price approach should be considered, such as using an oil supply curve or assume a simple (stochastic) exogenous price.

Model Development Context

The SEDS team developed a world oil module that simulates the impact of U.S. demand on world oil markets and the price of imported crude oil. The module includes uncertainty in future world oil prices by selecting between three oil price scenarios developed by the EIA in their 2007 Annual Energy Outlook[18] and by randomly including disruptions to supply. If the model user desires an exogenous oil price, one can be inserted in the current SEDS formulation.

SEDS Team Response

Oil price is a major driver of many U.S. energy markets, and the SEDS team agrees it is important to model it well. We have decided not to adopt for now the suggestion of using a "simple (stochastic) exogenous price" as our base approach. To do so would ignore the possible impacts that major shifts in the transport sector (e.g., the emergence of electric, biofuels, or hydrogen vehicles) could have on oil prices.

We have also elected not to base the price solely on an "oil supply curve" because of the inability of such curves to capture the geopolitics associated with a localized resource. Instead, we have opted to stay with our current stochastic representation of possible supply disruptions.

Difficulties with the Proposed Response

Inasmuch as the SEDS team does not feel any substantial changes are needed, there should be no difficulties with this approach.

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[18] Energy Information Administration (EIA) (2007). *Annual Energy Outlook 2007: With Projections to 2030. DOE/EIA-0383(2007*). Washington, DC: Energy Information Administration.

Timeframe for Resolution
No further resolution is required

2.2.16 Consistency between Modules (Milford)

Reviewers' Recommendation

> Ensure that there is consistency among components in various modules, such as ensuring that all of them include learning effects, adjustment costs, retrofits, etc.

Model Development Context
At the onset of SEDS development, the SEDS team felt it would be important to maintain a common framework among the end-use sectors and the energy conversion sectors. This framework included consistent learning effects applied to technology costs and performance, market share decisions, stock vintaging, stock retrofits, stock retirements, and stock energy requirements. We developed a template module to meet this need. As development in certain sectors proceeded, it became evident that a one-size-fits-all approach had its pitfalls. For this reason, several of the end-use and energy conversion sectors decided not to use the template but still held to the general methodology used in the template. Despite not using the template for all sectors, the end-use and energy conversion sectors are formulated nearly identically. The heavy-duty transportation sector is the only end-use sector that does not follow the general stock and flow structure, and the liquid (petroleum) fuels sector is the only energy conversion sector to not follow this structure. Instead, the heavy-duty transportation and liquid fuels sectors are based on a simplified econometric approach.

In addition, an R&D and learning-by-doing module was developed to accept the Portfolio Decision Support PDS distributions and learning rates produced by the expert elicitations. This module is consistently applied in all sectors tracking stocks of equipment or plants.

SEDS Team Response
At this time, DOE is not assessing the potential improvements in the liquid fuels and heavy-duty transportation sectors that are due to R&D, and therefore there is little need for the SEDS team to represent those sectors with the same detail found in other sectors. The SEDS team does acknowledge the importance of consistency in the areas that will be of most interest to DOE, and we will continue to maintain consistency as development progresses.

Difficulties with the Proposed Response
There are no difficulties with this approach, and it offers the advantage of simpler construction and faster run times.

Timeframe for Resolution
No further resolution is necessary.

2.2.17 Demographic Module (Sanstad)

Reviewers' Recommendation

> "Needs a demographic model rather than just population projection (immigration, urban/rural, age, work patterns, household composition, etc) especially since current trends and uncertain levels of household formation and immigration could lead to vastly different patterns of demand over time."

Model Development Context

The macroeconomic module incorporates exogenous aggregate population and labor force projections. This is a limitation for several reasons. First, in the Solow-type model, with labor productivity playing a paramount role, the composition and evolution of the labor force is critical for projecting long-run growth trends. Second, although this topic has received relatively little attention in the U. S. energy literature, trends in such metrics as aggregate and per capita energy consumption are known to be significantly influenced by key demographic variables, including the age cohort structure of the population and trends in household size.

In addition, while the Light Duty Vehicle module includes some age-cohort structure, the other demand modules do not. Thus, more demographic detail would be of use in the LDV module, and in principle in the buildings modules also.

SEDS Team Response

For the reasons just noted, we agree that incorporation of greater detail on demographic factors would be an important enhancement of SEDS. We have begun planning an enhancement in this dimension, tailored to the theoretical form of the SEDS macro module. We will develop a sub-module within the SEDS macro module that will generate mutually consistent projections of A) Labor force size and composition, and B) Age structure, household size, and possibly a small number of other key variables. The labor force projection will replace the current, exogenously specified trend in the SEDS macro module. The other information will be used to refine the specification of the macro module with respect to aggregate energy consumption, and in addition will be provided as an output to one or more of the SEDS energy demand modules. While the exact structure of this sub-module is still being planned, it will be based on U. S. Census Bureau long-run (year 2050) population projections.

Difficulties with the Proposed Response

To the extent that eventual use of demographic information by the buildings modules is a goal in principle, there may be substantial hurdles to revising the structure of these modules to incorporate such information.

Timeframe for Resolution

By September 2010, we will develop, implement, and test a demographic module, implemented as a sub-module to the SEDS macroeconomic module.

2.2.18 Stochastic Growth Model (Sanstad)

Reviewers' Recommendation

> The model currently lacks feedback on macroeconomics. It is not clear whether people want a macroeconomic model or just some sensitivities. A near-term macroeconomic module could be a driver; a long-term macroeconomic module could provide capital and labor implications

Model Development Context

As currently implemented, the macroeconomic module does not include explicitly stochastic elements.

SEDS Team Response

There is more than one type of "stochastic growth model" so in this sense the question is ambiguous. A stochastic dynamic general equilibrium model would require rational expectations and full model-horizon optimization, which is not possible using Analytica. Another possible interpretation of the reviewers' question is that something along the lines of an auto-regressive formulation was meant. We do not think that this type of econometric forecasting approach is credible on the time scale involved (i.e., the 2050 SEDS model horizon). In addition, a pure statistical forecasting approach either would partially or wholly preclude the use of the SEDS macroeconomic module for scenario exploration or "what if" analyses involving the influence of particular macroeconomic drivers on the energy system and on the effects of energy and greenhouse gas mitigation policy.

The reasons for the approach chosen are the credibility of the Solow model,[19] its very well understood theoretical properties, the fact that it can be closely tied to aggregate data on economic growth, productivity, population and labor force, and energy consumption, and the fact that key uncertainties in long-run growth that reflect uncertainties in a small number of underlying parameters can be well represented and thoroughly explored. In turn, these features facilitate the analysis of how macroeconomic drivers and uncertainties arising from particular sources propagate through the supply and demand simulations of the complete SEDS.

We are planning to explicitly represent these uncertainties in key parameters so that the macroeconomic module can generate stochastic results. We will initially concentrate on labor productivity and population growth, for which we will incorporate distributions. We plan to include stochastic capability as one simulation option, to complement the current direct-user input toggles on these parameters.

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[19] Solow, Robert M. (1956). "A Contribution to the Theory of Economic Growth". *Quarterly Journal of Economics* **70** (1): 65–94.
Solow, Robert M. (1957). "Technical Change and the Aggregate Production Function". *Review of Economics and Statistics* **3** (3): 312–320.

Difficulties with the Proposed Response

Because we will continue to rely on long-run population projections of the U. S. Census Bureau, it remains to be determined exactly how population growth rates should be treated probabilistically. The Census Bureau methodology is not formally statistical, and the Bureau emphasizes that its high and low projections are "cases" and not alternative forecasts, per se.

Timeframe for Resolution

We aim to have these parametric uncertainties included in the macroeconomic module by February 2010.

2.3 SEDS Team Conclusions

The SEDS team has reached some conclusions regarding both the conduct of a model review and the insights gleaned from this particular review.

The review process is clearly just beginning as SEDS develops and evolves, but several lessons can be drawn from the review process. First, the review helped solidify issues that, in many cases, were discussed within the SEDS team prior to the review. The review provided a sounding board for other opinions. Second, the time required to conduct a model review and to follow up is always limited. We feel that providing more inputs to the reviewers beforehand would have benefited the review. Because the review itself was also limited in time, a conscious decision was made to focus on the on the model capabilities rather than the data inputs. In hindsight, this was probably a mistake as technology costs were one of the more important concerns expressed by the reviewers.

Perhaps the most important review process consideration is the time to follow up after the review meeting. This is critical. In an effort not to sway the reviewers, the SEDS team took a hands-off approach during the final writing of the reviewers' report. To some extent, this left the reviewers in a vacuum in which they could not easily get questions about the model answered. In a few cases, this led to an inaccurate view of SEDS current capabilities.

The review was intended to improve the SEDS model. Improvements are occurring and will continue to occur as the SEDS team addresses the reviewers' comments. Our work on all areas the reviewers identified as being of high importance (e.g., equilibrium solutions, revised market share algorithm, decision-theoretic construct, improved costs, and model validation) is ongoing. All other recommendations from the body of the reviewers' report (e.g., regionality and life cycle impacts) have been considered or are under investigation. Some of these have already led to changes in SEDS (e.g., R&D focus of the opening screen), while others are in the process of being changed (e.g., modeling wind non-dispatchability as a function of the load met by wind). There are some recommendations (e.g., global scope), the SEDS team has investigated and decided not to pursue at this time.

The process of improving SEDS is a continual one; addressing some issues (e.g., equilibrium) can require significant resources. Some issues may require considerable time to resolve, while others have already been addressed. We expect that these improvements will continue in the future, not only in response to this review but also in response to other reviews and analytical uses of SEDS.

2.4 Response Schedule

Table 1 shows the timeframe for the response to individual comments in the body of the reviewers' report. This response and schedule has not been approved by the DOE sponsors who fund the SEDS development and analysis efforts. While there is broad support from DOE on responding to the reviewers' comments, there may be subtle shifts in priorities and timing based on DOE needs for SEDS and other projects to which SEDS developers must contribute.

Table 1. Timeframe for Response to Reviewers' Recommendations

Topic	Deliverable	Date
Equilibrium	New model	Sept. 2010
Market share	Include implicit costs	Sept. 2010
Foresight	Risk-adjusted discount rates	Jan. 2010
	Carbon allowance cost foresight	Sept. 2010
Decision-theoretic approach	Linear multi-attribute utility model for portfolio comparisons	Apr. 2010
	Explore 2-stage dynamic optimization	Sept. 2010
Better technology costs	Revised biomass supply curve	June 2010
	Consult other data bases	Feb. 2010
Links to other models	Comparison with AEO 09 on Wiki	Apr. 2010
	Comparison with EIA Waxman-Markey Bill analysis	July 2010
Initial screen focus on R&D		Sept. 2010
Regionality	Buildings module	Sept. 2010
	Other modules	Dec. 2010
More technologies	Criteria for selection	May. 2010
Expert risk elicitations	SEDS sensitivities on width and shape of distributions	July. 2010
Limit non-modeler changes	"Browse only" version with sanity checks	Oct. 2009
RE dispatchability	New logit formulation	April 2010
Display of case comparisons		April 2010
Display of stochastic outputs	Improvements	Dec. 2009
Display synergies, tech outputs, sensitivities	Expanded range of scenarios/sensitivities	Dec. 2009
R&D vs LBD	Comparison of learning between technologies	May. 2010
	Sensitivity to learning rates	May. 2010
Demographic and macroeconomic module	Macro economic uncertainties	Feb. 2010
	Demographic module	Sept. 2010

3 SEDS Reviewers' Report

In the report of their findings, the reviewers documented a wealth of valuable comments on needed improvements to SEDS. We re-present the report here in its entirety and unedited.

Reviewers

- Dallas Burtraw, Resources for the Future
- Jeff Harris, Alliance to Save Energy
- Robert Hugman, ICF Consulting
- Hill Huntington, Stanford University
- Revis James, Electric Power Research Institute
- Andy Kydes, Dept of Energy/Energy Information Administration
- Michael Leifman, General Electric
- John Maples, Dept of Energy/Information Administration
- Anthony Paul, Resources for the Future
- Bill Pepper, ICF Consulting
- John Reilly, Massachusetts Institute of Technology
- Constantine Samaras, Carnegie Mellon
- Robert Wallace, Penn State

Introduction to SEDS

The Stochastic Energy Deployment System (SEDS) model is a new energy market model that explicitly addresses uncertainties in future energy technology, markets and policy. The purpose of developing SEDS is to provide new uncertainty-related insights to Department of Energy (DOE) managers in the Office of Energy Efficiency and Renewable Energy (EERE), and potentially other non-modelers. These insights will help the DOE managers make more informed recommendations for federal funding of research, development, demonstration, and deployment (R&D) funding of energy efficiency and renewable energy technologies.

For understanding the national benefits that may be achieved by federal funding of R&D, DOE managers currently use estimates derived from a deterministic set of inputs about expected technology characteristics (i.e., technology goals addressing performance, cost, and dates of initial commercial availability) in the future. These estimates are currently made with limited consideration of the inherent risk and uncertainty in attaining R&D outputs and outcomes. Quantitatively addressing risk through a stochastic analysis could give added perspectives on estimates of future national benefits, can potentially result in more robust results from technology comparisons, and highlights the importance of a portfolio approach to R&D.

The overall objective for SEDS is to provide insights that will help DOE managers make recommendations for federal funding of EERE programs. The model is intended to answer questions such as:

- What is the likelihood that current federal budgets and R&D paths will achieve goals?
- How should a portfolio of R&D projects be balanced over risk, return, time, technologies, and markets to maximize objectives (e.g. reduced oil use, greenhouse gases emissions, etc)?

The goals for SEDS include:

- Explicit treatment of primary uncertainties including technology development, fuel prices, and policies
- Long-term R&D planning.
- Transparency, for data and methodology
- Quick-turn-around analysis, designed for use by non-modelers

These goals for SEDS determined the selection of Analytica (http://www.lumina.com) as the modeling platform. Analytica was chosen because it is a modular, user-friendly software package with relatively quick run times that is designed primarily for the explicit treatment of uncertainty in models. A brief overview of the SEDS model can be found at http://seds.nrel.gov.

SEDS has been commissioned by Sam Baldwin and Darrell Beschen within the Office of Energy Efficiency and Renewable Energy within the U.S. Department of Energy. As shown in Table 1, SEDS is being developed by a team of modeling experts for each sector, drawn from several DOE national laboratories and DOE subcontractors.

Table 2. SEDS Developers

Sector/role	Organization	Lead
Integration	NREL	Walter Short
Macroeconomic	LBL	Alan Sanstad
Buildings	LBL	Chris Marnay
Industry	PNNL	Joe Roop
Transportation	ANL	Anant Vyas
Liquid Fuels	ANL	Don Hanson
Electricity	NREL	James Milford
Oil	ORNL	David Greene
Coal and Gas	NETL	Don Remson
Biofuels	Lumina	Max Henrion
Hydrogen	Lumina/OnLocation	Max Henrion

The Review Panel and Process

This is the first review of SEDS conducted by experts outside of the development team. There remains work to be done to make the model usable by DOE managers, and this midcourse review is intended to identify and focus the remaining development efforts.

The invited reviewers met with the development team and other stakeholders for a day and a half on May 7-8, 2009. The reviewers represent a wide range of expertise in energy analysis and energy modeling, as noted in Appendix A.

The review meeting agenda is attached as Appendix B. Prior to the meeting the reviewers were provided access to a website that summarizes the modules of SED and drafts of the presentations. On the first day of the review the modeling team made presentations about the model and fielded questions. These presentations included an overview of the purpose and expectations by the DOE client, represented by Sam Baldwin of DOE/EERE, an overview of the model and extreme-case results by Walter Short of NREL, and detailed information on and results from each of the modules within the model by the person or team developing each module. The first day concluded with the group of modelers and reviewers breaking into smaller discussion groups to develop comments on the four specific questions posed to the reviewer team. The second day began with a discussion of the comments from each small group and concluded with the review team developing and sharing their core comments with the modelers and stakeholders.

Four Key Questions

The review team has addressed four questions posed by the model development team. These questions address the virtues and limitations of SEDS as well as the strategy for public release of the model. The questions and the review team comments on the questions follow in this section. These comments were generated through small group discussions followed by plenary review and further discussion. The comments do not necessarily represent a consensus among reviewers.

Overall, the review team feels that development of SEDS to date has been worthwhile and that after refinement and testing the model is likely to be a useful tool for R&D planning. At this point, there are no other U.S. modeling systems of this scope designed expressly to consider the implications of uncertainties related to federal energy R&D choices. Quantitative analysis of R&D choices is highly challenging as it requires an evaluation of the likely success of R&D dollars and the impact of those successes against a future that will depend on how all technologies advance. Often, R&D investments yield benefits in the distant future, provide insight and spillovers to other industries and technologies, or provide the R&D community with valuable information about what is not successful. All of these characteristics add to the challenge of defining success for an R&D portfolio. The combination of expert judgment on potential returns to R&D and a modeling framework to assess the implications of such success, recognizing that all technologies are changing simultaneously, and that these returns and the environment into which these technologies will be introduced is uncertain, the design plan of the SEDs system, is an appropriate and sensible approach. To be numerically efficient and computationally tractable requires inevitable simplifications and tradeoffs, as in any modeling exercise. A key consideration is the tradeoff between model simplification, the underlying analytical framework of the model and its ultimate usefulness.

What nationally important questions about technology development and the role of R&D will SEDS be able to answer?

The reviewers feel that SEDS is not currently ready to answer any questions and have therefore parsed this question into two parts. First, the reviewers consider the issues that SEDS will be ready to face once the current version of the model is sufficiently tested. Second, the reviewers consider the issues that SEDS could be equipped to address with further development within the existing model structure.

When the problems and issues regarding the current version of the model are addressed, it should, when fully developed and tested, be able to:

- Provide insights on risk and uncertainty for R&D planning for one technology or affecting one sector.
- Show the implications of different funding scenarios on national benefits, including magnitude and uncertainty of outcomes.
- Inform decisions concerning long-term and short-term R&D investments.

- Assess impact of learning assumptions among competing technologies; in other words, understand how all R&D learning affects relative costs and forecasts of deployment.
- The model can be an important complement to other forms of analysis to support national decisions about energy R&D planning.

Goals for further model development should enable the model to:

- Explore the outcomes of portfolios resulting from uncertainty around R&D investments by DOE and uncertainties in the environment.
- Assist in prioritizing DOE research.
- Allow evaluation of benefits in an uncertain world; for example, the consideration of the value of various options.
- Examine R&D policies related to demand-side management and other load shaving/shifting technologies, energy storage, and large-scale deployment and integration of RE technologies.
- Provide visibility about what supporting technologies may be on the critical path for a major technology; for example, with and without energy storage, or component technology learning.
- Use common assumptions and outputs with other major partial and general equilibrium models as boundary conditions for SEDS analysis.

What are the unique advantages of SEDS?

- Designed for portfolio analysis, not forecasting.
- Relatively simple, easy, and quick to use for experts.[20]
- More efficient generation of ranges of outcomes compared to scenario analysis or multi-model comparisons.
- "Big picture" view – focused on trade-offs associated with different portfolio strategies
- Model structure has flexibility to add new technologies easily.
- The large development team incorporates a diverse set of expertise.[21]
- Can be used to assess value of information, i.e. it can help identify the parameters to which the model outcomes are most sensitive and therefore demand most attention.
- Has the capability to evaluate uncertainties in multiple sectors simultaneously

[20] This point has engendered much discussion among the reviewers. Without dissent (or consensus) the reviewers acknowledge the virtue of a simple, quick model, but feel that the benefits of the requirement for a five minute solution are outweighed by the costs imposed by the tradeoffs required. One reviewer says, "I dislike this criterion since it undermines all others."

[21] This diversity can also create problems for the development team. This is mentioned in a bullet under the answers to the next question on limitations.

- Has more technology options in some end-use sectors than current models.
- Tool to explore sensitivity to assumptions about benefits of R&D investment, learning curves in planning. Very flexible, interactive tool for sensitivity studies.
- Create transparency and traceability in the value judgments and assessments underlying R&D portfolio planning.
- Introduces critical aspects of the electricity load curve while remaining numerically efficient.

What are the important limitations of this model or modeling approach and what improvements should have high priority before the next release?

We have made more extensive comments in response to this question than any of the others, reflecting our desire to see this model successfully completed and released. We have not prioritized our comments.

Inputs

- The distributions and parameters chosen to represent stochastic variables are themselves uncertain and will influence the model results. Every analysis performed with this approach should carefully state this caveat since the selection of the distributions and their parameters could imply the model contains more information than it really has.[22]
- Needs better underlying data on technology and supply chain cost info (e.g., biomass technology has complex costs, some gaps in cost info).
- Needs a demographic model rather than just population projection (immigration, urban/rural, age, work patterns, household composition, etc) especially since current trends and uncertain levels of household formation and immigration could lead to vastly different patterns of demand over time.
- Update the inputs frequently to keep the model current to policy and technology expectations.

[22] Andy Kydes notes that the Identification and use of the appropriate probability distributions are themselves sources of uncertainty. There appears to be no real reason to believe that one type of distribution with specific parameters is better at representing the true underlying distribution than another. (We all recognize that random sampling from most distributions (with a few exceptions like Cauchy) will ultimately approach some normal distribution as the sample grows infinite in size.) One can only know the true underlying distribution by sampling from a revealed distribution about the past for the specific activities. My understanding is that this approach is currently not being used. Thus, placing a high value on the stochastic results when the source of the distribution was either an assumption or developed by sampling of "experts" who may or may not be experts or unbiased could be misleading, unreliable, and prone to gaming which would undermine any results related to cost, benefits and robustness. The users of SEDS should very carefully consider how the distributions were derived and carefully caveat potential bias issues in the analysis. Also, the modelers should acquire and study the EU sponsored project on 'learning through R&D". The acronym for the project was called SAPIENT with Dr. Capros (or Mr. Kouvaritakis) from the National Technical University of Athens and IIASA being a major participants.

- Ensure that expert input considers how Federal R&D funding and policies (e.g., carbon tax) could impact private R&D investment, and also the impacts of non-U.S. groups doing technology R&D.
- A simpler oil price approach should be considered, such as using an oil supply curve or assume a simple (stochastic) exogenous price.
- Scope of modeled technologies needs to be more comprehensive.
- Need to better represent consumer behavior in modeling.
- The size and diversity of the development team may make management difficult. For the advantages of the team's size and diversity to be realized, the development team leader may be required to use a strong hand to bring cohesion to the model as a whole.

Model Capabilities

- The failure to solve for equilibrium in each period is a serious problem. The review team identifies this point as among the most important. The non-convergence creates more difficulties in interpretation when the stochastic version is used.[23]
- The lack of an intertemporal, optimization framework means that results have to be interpreted with care. The expectations used in each market should be represented according to how each market makes decisions. This will vary by market segment. The use of myopic expectations in every market is a serious flaw that needs to be corrected.
- Results would be improved by adding the capability to analyze and communicate life-cycle impacts (e.g,, land use change, manufacturing of materials that originate outside the US that are not in the industrial sector module such as batteries, investment in rail, road, pipeline, and electricity transmission infrastructure, fuel extraction and refining).
- SEDS needs a much better market share/market diffusion formulation/technology choice formulation than the one used in the electricity market and perhaps elsewhere since the current version cannot be calibrated well enough to simulate technology choices in the energy market; important non-price factors and consumer preferences are not represented in most, if not all, of the current choice functions. Without making this correction, it is unlikely that the SEDS model can be reliably used for technology assessment.
- The model is a single region model with average characterization for everything (technologies, prices, etc). Such a regional characterization is poorly positioned to do policy analysis or technology assessments. The model should be regional if serious policy analysis and technology assessment applications are contemplated.

[23] Some reviewers feel that the non-equilibrium nature of SEDS, or at least the lack of a theoretical basis for disequilibrium within the model, renders the solution a truly random outcome that is not useable to inform R&D decisions.

- Extending the timeframe through 2050 creates a problem in that the uncertainties that far in the future will essentially overwhelm meaningful output. This may be an unavoidable issue if it is necessary to extend the timeframe to 2050 to show the impact of long-range technology options of interest to DOE (e.g., FutureGen, hydrogen). This issue can be partially addressed by using the model to perform sensitivity studies so that the effects of uncertainties can be explored.
- A global model would be superior to the current U.S.-only model since many energy and commodity markets are global. However, the reviewers acknowledge the run-time problems that a model like this might engender.
- The model currently lacks feedback on macroeconomics. It is not clear whether people want a macroeconomic model or just some sensitivities. A near-term macroeconomic module could be a driver; a long-term macroeconomic module could provide capital and labor implications.
- Policies will affect R&D spending, but it is not a model designed to thoroughly analyze the impacts of policy changes. The review team feels that this a very important caution so that the intent of the model is not misunderstood by those using it.
- The model is, by design, not as capable as other systems to measure impacts on jobs and other macroeconomic outcomes of R&D investment.
- The current lack of accounting for behavioral or institutional barriers to adoption limits the model's usefulness. For example, technology adoption could be hampered by a limited workforce, a "not in my backyard" social response, or other aspects of consumer/investor decisionmaking, etc.
- The model should ensure that more subtle aspects of technology costs are properly accommodated, such as the relative non-dispatchability of some RE sources. An example would be to indicate one cost if wind and solar are 20% of total electricity, or a different cost if they constitute 40% of total electricity.
- Ensure that there is consistency among components in various modules, such as ensuring that all of them include learning effects, adjustment costs, retrofits, etc.
- The choice of parameters and logit formulation for market share is critical, and may not be consistently developed in all modules. In fact, the market share formulation, particularly for the electricity sector, represents a serious flaw in the SEDS model for technology choice and market diffusion of technologies. See appendix C3.

Outputs

- The model does not seem to have clear common metrics that can be used to compare technology impacts. Consider using net present value wherever possible for quantitative economic effects. The model needs a coherent decision-theoretic approach to compare R&D investments. The review team identifies this point as among the most important.

- Based on preliminary results, the technology costs may not be realistic – recommend expanding sources, e.g. EPRI, IEA. The review team identifies this point as among the most important.
- The results from SEDS should identify the economic opportunity space for decision-making, such as an upper or lower boundary where it is economically viable to "do things."

How should this model be publicized and distributed, when it is ready for public release?

- The model should be released after the major model issues that are identified by the reviewers have been addressed and the results are more fully developed and tested, including a description of how the model responds to key inputs/changes. Strongly suggest that a selected set of SEDS analyses designed to address known, existing analyses by other models be done. The results will allow a thorough characterization of capabilities and limitations. Look to macroeconomic analyses done as part of US Climate Science Program, IPCC, and others.
- Needs thorough documentation and an excellent user guide. No matter how well documented, DOE would need to be prepared to provide support in response to policymaker and/or general user questions.
- The distribution of this model should be limited to experts who know how to run the model and interpret the results correctly in order to minimize misuse and abuse. Initially, the model should be used by the sponsors and the sponsoring office to ensure that the model is providing useful information.
- Initially at least, the model should be released with limited functionality, or limited options for user manipulation. Either non-modelers should not be able to change parameters unrealistically, or some assumptions should not be able to be changed.
- Should consider releasing it in the form of a multi-scenario study with emphasis on the results, not the methodology
- Open-source release could have advantages for the long term, such as getting broad feedback, encouraging and supporting modeling research, and potentially adding new modules.

Other Comments

Expert elicitations

- Follow the established procedures and protocols of conducting peer-reviewed expert elicitations.
- Ensure that the experts chosen to give input include a cross-section of those with knowledge of energy and related markets. Be sure that there are inputs not only from technology developers, but also from end users, etc.
- Ensure that there are sufficient resources for the experts providing input.
- Expand the expert evaluation of R&D benefits and learning by doing assumptions.

- Experts are not expert at probabilities and projects. Provide training for the experts as well as those doing the elicitation, or continue providing training. Develop a plan for updating inputs from experts so they will stay engaged with the process.
- For clarity, identify which distributions were developed through the independent expert process.
- Characterize and summarize how the literature quantifies successful outcomes of past R&D investments[24], in addition to taking expert opinions on future impact of R&D investments.
- This model requires continued linkage to robust technical risk analysis and reliable determination of good bounds for other key lever inputs.
- To the extent possible, ensure level of optimism/pessimism of R&D assumptions and impacts (cost, performance, date of availability) are derived consistently.
- The study of past R&D investments, when available, should be the primary source of information for determining the impact of future R&D investments. The EU has sponsored a long-term study on "learning through R&D" (SAPIENT) and the program offices should make every effort to acquire the details of that study and possibly use the lessons learned.
- Draw on experts from outside of DOE.

Communications

- The outputs need more attention to graphic design to properly show the stochastic results.
- Consider developing ways to assist users in seeing synergies, interactions, and sensitivities among technology programs within the DOE portfolio. Users should be able to see contributions of individual technologies to outcomes such as CO2 reductions.
- The model should make it easy to compare various cases.
- The first input screens seem too policy focused, given that the model is intended to help DOE managers with R&D investment decisions. Screens on R&D funding should be up front.
- A fundamental communications issue with this approach is that the basis of the R&D and LBD curves from experts will be hard to explain in a concise manner. Thus understanding what is driving the results will be complex to communicate. This issue has to be addressed or SEDS will constantly be crippled by misinterpretations.

Other

- This is a tool for R&D planners, not for policy analysts but the temptation to (mis)use it for policy analysis is inevitable. Sponsor and developers must recognize that and consider appropriate actions to minimize the damage to the energy policy debate,

[24] Costa Samaras noted that Julie Lane at NSF has begun to assemble such a study recently.

including limiting the versions and features released and printing a caveat on all output reports that are programmed to the system.

- For addressing carbon cap impacts, consider just looking forward and cycling for 5 or 6 years, rather than the full time horizon. This would allow getting a better view of the results, without increasing run time too much.
- Consider adding model convergence or a formalized disequilibrium criteria that the model solves for, including appropriate expectations by energy market segment when making investment decisions.
- Ensure the model has the capability to turn modules off and run individual modules diagnostically.
- Ensure that the model can run parametric sensitivities to understand results.
- The model may not need to be calibrated to DOE Energy Information Administration's Annual Energy Outlook, but simply to explain where the model deviates.
- Validation of the model is important to consider. At the outset, set a mechanism or review process to determine if
    - R&D improvements anticipated by experts were realized.
    - Using SEDS was effective in influencing R&D portfolio.
- Note that SEDS should not be a "traditional" model. It is not "NEMS with error bars."
- Managing the development of SEDS requires a strong leader and a clear process to make decisions on functionality and capability changes as the development progresses.
- The SEDS modeling team should formalize relationships with other modeling teams (CIMS, NEMS, MARS, etc). Some parts of these modules could feed information into SEDS to reduce development time and cost.

[Reviewers'] Conclusion

The reviewers are impressed with the progress made by the SEDS development team. In particular, the review team feels that the model is well conceived to address the primary objective of SEDS, which is to improve the information at the disposal of EERE for R&D decisions by beginning to incorporate the inherent uncertainties. The model has not yet satisfied this objective, but the reviewers feel that with further development and testing, attainment of the goal is within reach.

The reviewers identify the critical issue going forward as the trade-off between optimization rigor and computation time. Many of the modules within SEDS, and the system as a whole, do not find an equilibrium. This construct is deliberate to keep computation time within a five minute limit so that the model may be widely used. However, the lack of an economic stopping criteria (equilibrium or disequilibrium) is a serious issue limiting the usability of the model for the stated purpose and should be corrected. The review team feels that SEDS is so large and complicated, and that the opportunity for unsophisticated users to draw faulty conclusions is great enough, that relaxing the five minute time constraint might be desirable.

Appendix A: List of Attendees

SEDS Model Developers:
David Greene, Oak Ridge National Laboratory
Don Hanson, Argonne National Laboratory
Max Henrion, Lumina Inc
Olga Livingston, Pacific Northwest National Laboratory
Chris Marnay, Lawrence Berkeley National Laboratory
James Milford, National Renewable Energy Laboratory
Deena Patel, University of Michigan
Don Remson, National Energy Technology Laboratory (unable to attend)
Joe Roop, Pacific Northwest National Laboratory
Alan Sanstad, Lawrence Berkeley National Laboratory
Walter Short, National Renewable Energy Laboratory
Surwa Swamy, Lumina Inc (unable to attend)
Anant Vyas, Argonne National Laboratory
Frances Wood, OnLocation Inc

Reviewers:
Dallas Burtraw, Resources for the Future
Jeff Harris, Alliance to Save Energy
Robert Hugman, ICF Consulting
Hill Huntington, Stanford University
Revis James, Electric Power Research Institute
Andy Kydes, Dept of Energy/Energy Information Administration
Michael Leifman, General Electric
John Maples, Dept of Energy/Information Administration
Anthony Paul, Resources for the Future
Bill Pepper, ICF Consulting
John Reilly, Massachusetts Institute of Technology
Constantine Samaras, Carnegie Mellon
Robert Wallace, Penn State

Other Participants:
Bill Babiuch, National Renewable Energy Laboratory
Sam Baldwin, Department of Energy
Fred Beck, Sentech
Darrell Beschen, Department of Energy
Lynn Billman, National Renewable Energy Laboratory
Thomas Jenkin, National Renewable Energy Laboratory
Mona Khalil, Sentech
Gian Porro, National Renewable Energy Laboratory

Appendix B: SEDS Review Agenda

May 7-8, 2009

490 L'Enfant Plaza, SW, Suite 3207, Conference room B
Washington, DC 20024-21
Local land line: Brenda Davis, ANL DC, 202-488-2400
…………………..

Thursday May 7

Session I

7:30 – 8:00 am	Continental Breakfast
8:00 – 8:10 am	Welcome and introductions (Sam Baldwin, DOE)
8:10 – 8:20 am	Agenda/review questions (Lynn Billman – NREL Facilitator)
8:20 – 12:00 noon	Presentations

- Purpose/need for SEDS: Sam Baldwin (10 min)
- General approach, current status, general results (60 min)
- Electricity (30 min)
- Break (15 min)
- Buildings (25 min)
- Industry (25 min)
- Transportation (25 min)
- Oil price module (20 min)
- Break (10 min)

Session II

12:00 – 12:30 pm	Lunch (served in the meeting room)
12:30 - 1:00 pm	Questions from Reviewers

Session III

1:00 – 4:00 pm	Presentations (continued)

- Coal and gas (25 min total)
- Biomass, Biofuels, and Hydrogen (25 min total)
- Liquid fuels (20 min)
- Macroeconomics (15 min)
- Demonstration of SEDS (35 min)
- Questions from Reviewers (45 min)

- Break (15 min)

Session IV
4:00 – 5:45 pm Small group breakouts

Groups will be assigned. Each group answers the following four questions. Suggest one slide with comments for each question from each group.

1. What nationally important questions can this model answer for decision makers?
2. What unique value and advantages does this model bring to the energy modeling community?
3. What limitations does this model or modeling approach have, as it exists today? What changes and improvements are mandatory or high priority before the next release?
4. How should this model be publicized and distributed, when it is ready for public release?

Thursday May 7 Dinner (optional)
6:30 pm L'Enfant Plaza Hotel, American Grill. Reservation under Lynn Billman.

Friday May 8
Session I
8:00 - 8:30 am Continental Breakfast
8:30 – 9:45 am Small group results

For each of the four questions in turn, the leader of each small group will share the primary comments from his/her group. (15-20 minutes per question)

9:45 – 9:55 am Break

Session IIA
9:55 – 11:10 am Reviewers prepare their conclusions in slide format, using the four questions for the report structure. (Facilitated by Lynn Billman as necessary.)

Session IIB
9:55 – 11:10 am Modelers and observers discuss small group results and overall SEDS future direction

Session III
11:10 – 12:00 Reviewers present their conclusions to the modelers and observers
12:00 noon Summary of next steps

Review Report:

NREL will translate reviewers' slides into a Word document draft report, adding explanatory material as necessary to complete the report. The Lead Reviewer will coordinate reviews of the document and get approval by the reviewer team. This will become the final report of the SEDS Review, authored by the reviewer team. Target date for this report is May 26, 2009.

Appendix C: Comments of Individual Reviewers

Appendix C.1: Comments of Hillard Huntington

Since many of my comments are already well expressed in the main report, I will focus my attention on overall model architecture. The "curse of dimensionality" was well articulated at the meeting: region, time, technologies, multiple equilibria, etc. At the risk of oversimplifying the problem, I see two main modeling approaches that could be employed:

- The decision analysis approach would focus on multiple technologies with different performances and success rates as well as other key uncertainties.
- The general equilibrium approach would focus on multiple market balances that interwove with each other in complicated ways.

SEDS tries to walk a delicate path between these two approaches. It does not really solve the general equilibrium approach but it does allow prices to change over time as supplies and demands gradually search for a balance.

After two days of reviewing the model and its approach, I see SEDS as a way to develop a new modeling strategy that would focus more on the decision analysis than the general equilibrium approach. This view is consistent with the remarks at the meeting about treating world oil and macroeconomic developments as uncertainties rather than as modules and considering prices by energy sources to be a fixed distribution of outcomes rather than market determined. As an economist, I would love to see the model determine prices, but that approach may require you to give up on other valuable features.

One strategy would be to keep the price distributions fixed initially (essentially making all energy supply curves perfectly elastic to price). Use the model to solve the technology portfolio problem for a given set of energy and carbon price distributions. Check those simulations with output from a general equilibrium model to see how much energy prices would change if energy demands were constrained to look something like what SEDS chooses. If necessary, SEDS would be simulated again for a different set of energy price distributions that are more consistent with the general equilibrium results. To avoid continual iteration between the two large systems, I view this process as being approximate attempts to avoid the first-order problems rather than being tied to strict convergence criteria.

Over time, the SEDS modeling team may learn that the new technologies under consideration have a very pronounced effect on some prices (carbon-free sources relative to carbon-based sources) than on others. These linkages might be built into SEDS using simple rules of thumb that avoided a full general-equilibrium treatment.

In addition to model architecture, I would like to add two more points. First, I strongly concur with John Reilly's fifth point that the analysis needs to address the relationship between technologies being developed by DOE with those being developed by other research groups. I think that this point should be emphasized in the main summary report.

Second, the modeling team needs to provide sufficient representation and thought about some of the older energy technologies, like unconventional oil and gas production and opportunities to improve the internal combustion engine, with the same enthusiasm for the new technologies featured in DOE’s portfolio.

Appendix C.2: Comments of Revis James

May 6, 2009

- The whole thing hinges on a couple of key factors:
    - The R&D and LBD curves driving technology costs over time are accurate – sounds like they're depending on **DOE** expert elicitation for these – not sure if the expert pool includes others, though.
    - That seeking a price-driven equilibrium between supply and demand for energy will result in a sound basis for informing R&D priorities.
    - Sounds like the array of current/future technologies isn't comprehensive, e.g. no gas to liquid. One validation of this observation is Walt Short's comment that in their CO2 policy case, they couldn't achieve 80% below 1990 levels by 2050 with the current technology set.
- Essentially, SEDS is a tool to translate expert opinions on benefits to specific technologies of R&D, LBD into quantitative terms, albeit probabilistic terms. Their philosophy is that an order of magnitude understanding of the response of achieving benefits to different R&D priorities and investments is key for DOE decision makers.
- Fundamental communications issue with this approach is that the basis of the R&D and LBD curves from experts will be hard to explain in a concise manner. Thus understanding what is driving the results will be complex to communicate.
- They are using AEO cost data – need to expand their technology cost database.
- Their approach to handling load curve is interesting – could apply in MERGE.
    - Define a preset number of load "regions" in which amount of energy is defined in % terms of total energy.
    - Define an average CF for each region as a ratio of the energy in this region divided by the energy if the capacity in that region were to operate for 8760 hrs.
    - Calculate LCOEs for each generation technology based on the region CF and other cost characteristics – lower CFs => higher LCOE
    - Compete technologies against one another in each region – self-selects baseload and peaking due to the CF.
- The model is national, not regional.
- What is the schedule?
- Seems like the fuel pricing modules are somewhat weak, but not sure.
- Macro-economics module calibrates to AEO. Key is how to treat uncertainty in conjunction w/estimates of GDP impact.
- CO2 emissions constraint options allow flat or monotonically declining constraints.

Overview

- NOT an optimization tool, but a simulation tool – thus stochastic. How do we determine if the parameters determining statistical behavior are accurate?
    - This is a key issue – apparently what is meant by "not optimized" is that the model is not an intertemporal model, i.e. it doesn't have perfect foresight.
    - Logit models are thus used to determine technology market shares. This basically handles the "knife-edge" price-driven technology split issue.
        - The issue here is the choice of α, which determines the degree to which the logit curve is "knife-edge": large α => more knife-edge behavior.
    - Time horizon is 2050.
    - Attempts to converge on an equilibrium over time – "equilibrium" is defined as a balance in energy production and consumption as determined by price.
    - An important question raised by John Reilly/MIT is that how does one represent investment expectations (which ultimately drive decisions). Answer is that prices are projected based on past behavior. Reilly noted that this makes analysis of potential policies problematic. Not sure how the model deals with this. Essentially, as the model builds up future behavior, that behavior becomes the basis for projecting future conditions. Basically, lack of intertemporal modeling sounds like a problem re: policy option analysis.
- No macro-economic feedback => no feedback loops such as fuel switching, trade-offs between electric and non-electric energy?
- Has alpha-testing including vetting analysis results against other models?
    - One issue that was raised is that the extreme sensitivity cases used to test the base case (e.g. high oil, high gas prices) – sounds like they fix a price without changing another fuel that may in the real world correlate to the fuel prices that has been raised.
- What is the nature of the independent testing and the organizations to be used?
- What is the generic method by which the impact of R&D and learning by doing (LBD) reduce costs over time?
    - They get the R&D part of the curve from DOE experience/expert elicitation.
    - Expert opinion is the basis of the LBD curves and their probabilities – thus it is possible that an LBD curve resulting in higher costs can result.
    - Sam Baldwin observed that the LBD curves could/should reflect other externalities, e.g. problems with scalability, etc.

- John Reilly comment (very good one) was that LBD isn't solely a time phenomenon, e.g. overly rapid deployment can cost more, early monopolizing of technology/IP before widespread deployment, etc.

- Is the determination of stock vintages (e.g. how many, ages, etc.) an input?
- Carbon prices are inputs or outputs? Same question for fuel prices?
- Don't understand the energy prices shown for the base case - ~$80/MWh – actual costs are more around $70/MWh. Similar question re: total US CO2 emissions – I believe that we're currently already around 7000 mmT CO_2, while model results show this level being reached in 2040-2050.
- Is land use competition reflected in model (particularly important for biomass?)
- If I'm reading the delta charts correctly, the error bars seem pretty huge.
- Generally, are subsidies included? Why or why not?

Macro-economic Module

- Are the methods, assumptions standard, e.g. compatible with general equilibrium models like MERGE, ICAM, etc.?

Electric Module

- Are the methods, assumptions standard, e.g. compatible with general equilibrium models like MERGE, ICAM, etc.?
- How many customer types/groups?
- Just to confirm, no treatment of added capacity requirements for reserve margin? See note below on load shape.
- "Static load shape" means flat, or curved but seasonally invariant? Looks like a standard curved shape that is invariant.
- They have assumed "instantaneous build".
- They use national reserve margin of 15%.
- How are grid integration, transmission costs handled for variable output resources?
    - They do add some cost for some degree of additional capacity to offset wind variability.
- Don't understand slide 11 – where are capital costs, and why is T&D such a large fraction?
- EPRI capital cost, LCOE cost numbers could be a resource.
- Interesting stochastic results – utility would seem to be that one can evaluate to what extent different scenarios are or are not substantively different.
- Coal (both PC, IGCC), Gas technologies including CCS part of the analysis?

Coal & Gas Module

- Shale gas included? – No

- Is the oil/gas, oil/coal price correlation a valid basis going into the future?

Biomass, Biofuels, H_2 Module

- Looks like land availability, agricultural practices still need to be incorporated?
- For H_2, is H_2 as an energy storage resource for electricity represented elsewhere in the model? If yes, is this module linked to energy storage, electricity modules?

Buildings Module

- Could use EPRI Efficiency report as a resource for assumptions about technology penetrations.

Appendix C.3: Comments of Andy Kydes

Now that I have h***ad a chance to thi***nk about what I have seen and heard about SEDS, I have developed some serious concerns that I want to express on the modeling. The fundamental intended use of the model seems to be to provide assistance in making R&D investment decisions given the uncertainties of successful R&D and the uncertainties of the market conditions. This is a worthy goal but may not be not achievable using the SEDS model as currently characterized.

Concerns on the Modeling

The model appears to resemble the old LEAP model developed for EIA by Dave Cazlet (sp?) and Dale Nesbitt in that it uses a logit formulation to determine market shares of competing technologies for any service or sub-service.

- *Unlike the LEAP model*, the SEDS model does not guarantee an energy market equilibrium and the solution algorithm is not based on some theoretically designed market *disequilibrium solution that moves toward equilibrium*. The solution appears to be random; supply and demand do not necessarily match except by chance or by rerunning the model a number of times by the analyst to better approximate an energy market equilibrium.
- The disequilibrium problem can get much worse in the stochastic solutions case since each stochastically derived solution will also be randomly un-equilibrated and the analyst cannot be certain what results of the stochastic solution are robust and which just happened that way because of the series of en-equilibrated solutions.
- That is, the value of the stochastic approach is greatly diminished if not eliminated by the lack of convergence in the solution process for both the deterministic and the stochastic approach.
- The fairly well-known properties of the market sharing algorithm make it hard to estimate and use effectively for the purposes of the sponsor:
    - The market share formula is related to a Weibull distribution on prices;
    - Market shares of competing technologies are equal at equal prices with no quality or behavioral parameters to alter the price-induced shares;
    - The market share formulation generally does not mimic market behavior well.
    - The market share formula[25] yields shares that are critically dependent on the magnitude of the exponent used in the share equation and the estimation of the exponent has been problematic;
        - at large values of the exponent (γ), the technology selection mimics LP decisionmaking;

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[25] The simplest form of the market share formula is: $\text{Share}_i = P_i^{-\gamma} / \sum_j P_j^{-\gamma}$

- at some values of the exponent (generally 1 or less) every competing technology gets a sizable share regardless of the price (see table 1 for an illustration);
- the algorithm is susceptible to the "red ball, blue ball" problem in that if you introduce the same technology twice in the sharing algorithm, its market share increases which is probably unrealistic since it is not a true competitor.

Table 3. Gamma, Prices and Market Shares

Price ($/MMBtu)	Gamma = 1 Market	Gamma = 10 Market Share
1	0.386	0.999
2	0.193	0.001
3	0.129	0.000
4	0.096	0.000
5	0.077	0.000
6	0.064	0.000
7	0.055	0.000

- A slightly better formulation with greater flexibility is the following:

$$\text{Share (techi)} = (Pref_i * P_i^{-\gamma})/(\sum_{j=1}^{n} Pref_j * P_j^{-\gamma})$$

where $Pref_i$ is the preference for that technology at equal prices for all technologies. The value of Pref would be 1/n if there were no preference which is what is used in the current version of SEDS.

Even this form is seriously flawed unless the modelers can develop a theory on how the $Pref_i$ might dynamically change as a function of time and other parameters; for example (just an example) , $Pref_i(t)$ = function (share(tech j)$_{t-1}$, $P_j(t)$, $P_j(t-1)$). Notice that the $Pref_i$ should be positive if they are really competitors. It is not necessary that the $\sum Pref_j = 1$ although it would be convenient if they were so. Notice that you can "normalize" the Pref by dividing the initial selection of preference functions by their initial sum.

- The project suffers from scope creep and it is clear that the various developers often have totally different concepts of what the modeling goals and capabilities of SEDS should be. That suggests uneven development and expectations of applicability and result in a misuse of the model. That tension has to be resolved and the goals agreed upon by all collaborators.

- The model is national in scope. The model uses average characterizations for technologies which are likely to distort the policy impacts, R&D impacts, and technology adoption.
- In my view, the model is **not** ready for use for any policy analysis or technology assessment purpose at this time. The problems identified are, in my view, serious and must be addressed before the model can be applied to R&D investment decisionmaking that could affect tens of billions of dollars.

ASK/(5/22/2009)

Appendix C.4: Comments of John Reilly

The quantitative analysis of the R&D portfolio decision—How to allocate R&D dollars among competing projects?—is an exceedingly challenging task. It presumes that one can project the success of incremental changes in R&D spending for hundreds of technologies where the "benefit" of R&D for a technology or small set of technologies in terms of commercial success (and reductions in the cost of supplying energy that meets environmental and other goals) depends on success of all R&D projects as well as a host of other uncertainties (economic growth, the evolution of policy, fuel and energy prices, etc.) where those uncertainties may be partly due to completely exogenous forces and partly a response to the success of energy R&D being modeled.

I would argue that the test for such a system is not whether it can actually do this accurately but whether it can systematically integrate well-known and agreed relationships and principles with the inevitable need for judgments on the likely advance of technology for an incremental dollar in a way that is transparent and invites discussion and debate about key elements that can be evaluated. In that way, one can hope to provide some firm guidance on R&D spending. For example, if the modeling shows that a determining factor in R&D returns among competing technologies turns out to be the size of the market to which they apply, or that there appears little chance that R&D will ever bring costs of some technologies within commercial range then that would be a solid reason for more potentially reallocating budgets (following perhaps more scrutiny and debate about whether those elements of the system are approximated well in the model or not). I wouldn't expect there to be complete agreement on these issues but just focusing the debate on issues where objective evidence and reason can be brought to bear is useful.

Some important issues:

1. As described in the review session, the model appears not to achieve equilibrium in markets in each period. This is a relatively serious problem, and in general is not acceptable modeling practice. The argument that the world or markets are not in equilibrium is not a defense here. The lack of equilibrium in a numerical model is a failure of the solution routine and so there is no reason to expect this to represent some real world behavior. Equilibrium simply means that producers and consumers are seeing the same prices and that all supply forthcoming at that price is accounted for. Real world "disequilibrium" may involve building or depleting of inventories, unemployment of resources or idle plant and equipment, prices that do not recover the full cost of production (including sunk costs) etc. but there are not unbalanced sinks and sources for goods and money as is the case when a model fails to achieve equilibrium. Given all the SEDs model is trying to do I understand the desire to not iterate to find an equilibrium solution. My recommendation would be to assume prices are stochastic but given in each resolution of the model, and that there are net exports or imports into the US to meet supply or demand gaps. While the US is a large market its affect on world prices is limited. The stochastic border prices can cover the range of possible prices as they might be driven by many different assumptions about what is happening abroad—the actual feedback from what happens in the US is a quite

small component of the likely price variability. For example, across a quite different set of domestic policy actions that affect oil use in the US, we might see a 5% impact on the world oil price. That is dwarfed by the fundamental uncertainty in oil prices where reasonably prices could be double or triple what they are today in a few years or one-half or one third. Gas and coal prices are not fully determined in a global market but I suspect this is also mostly not as important as some would believe. It would be useful to analyze the degree of correlation in prices for particular fuels in different regions over long time periods. I expect it would be quite strong suggesting indirect if not direct linkage through a single world market. There are many reasons why wedges may create absolute differences in prices but the determination of whether the problem can be approximated by a single market is whether the prices are strongly correlated (and thus the wedges remaining relatively fixed).

2. The lack of stochastic GDP growth is peculiar and seems generally inconsistent with the uncertainty focus of the model. I would change this soon.

3. I think it would be extremely useful to calculate an explicit monetary rate of return on R&D investments based on the cost savings in reduced energy costs (or an economy wide measure of welfare if the link back to the macro-model component can be completed). I realize there are many people who like to imagine that there are multiple policy goals that an R&D program might solve that are incommensurable such as creation of jobs, energy security, environmental benefits, etc. Much of this thinking is not well grounded or one can develop approaches that sensibly reduce the problem to cost-savings. (e.g. if you assume a particular environmental goal you can reduce the evaluation of R&D returns to a comparable economic return on a cost-effectiveness basis—how much do you save while meeting that goal, which itself could be an uncertain target—even though you cannot value the avoided damages of the environmental goal. Leaving the issue of benefits to dozens of metrics that are the choice of the user or policy maker does not go far enough in terms of enforcing known and well agreed economic decision criteria. I would like to see the ability to say the mean rate of return on investment in technology x is 25%, in y is -10%, in z is 150%, etc. based on economic returns. This ought to be the main criteria for ranking and reallocating R&D. Formulating the problem in this way would bring clearer thinking to the problem—then we have a clear basis for choosing an optimal portfolio for a given level of spending—that is to allocate spending to R&D such that the rate of return is equal across all technologies. I don't think the model is at this point capable of doing that calculation, and I think it would take a lot additional work to make it produce such a result—for example, the returns to R&D needs to be reformulated as a continuous function of spending rather than just a couple of different levels. The model can contribute as it is but moving toward a specific estimated rate of return would make it much more compelling. Such a formulation is more realistic in terms of what decisions at the highest level are: Given a budget that Congress has passed or has been given in OMB guidance DOE must decide how to allocate it. That is not a decision to spending everything on a some things and nothing on others but finding those to expand

and by how much, at which one's expense. And, if the average rate of return remains very high when allocating the budget, then that is an argument to go back and say that many projects that could generate a high return are going unfunded. As I noted this will take some more work, but it is within reach if it is seized as a goal of the project.

4. I intended to support Andy Kydes concern about the logit formulation. Many of these share formulations are crutches for modelers as they pretty much assure that every technology gets at least a piece of the market, and it can be argued that we often see a diversity of technologies and so such a result is more "realistic" than a winner take all result. While there are good reason for some exceptions, I believe that many markets are winner take all markets and when we see a diversity of technologies supplying that market that is that results from not being in a long run equilibrium. In a highly aggregated model the share formulations can capture different essentially different markets—baseload, versus shoulder or peaking—demand for lighting in housing versus space conditioning, etc. To its credit, the SEDs model has a pretty explicit treatment of these different market niches and so I think you can get diversity of technologies because of the diverse demands. The logit formulation seems too likely to create or preserve share for technologies that are dominated by others, and conversely limit the economic potential of those that should be dominating. Since the main purpose of SEDS is stochastic modeling you will get some value to weak technologies—they may be successful in 10% of the cases. I'd rather see them getting 100% market share in 10% of the cases and zero in the other 90% than creating some logit function so that you get at least a little bit of everything in every scenario even though in reality they are not viable in many of them.

5. A crucial consideration of Federal R&D is how those expenditures fit within total R&D expenditures for energy research. Expenditures by foreign governments are important as are expenditure by private industry. The SEDs analysis framework does not address this issue very well. At best we heard that the experts that were elicited on what could be obtained from Federal R&D were coached to view this as additional to what was already being done (presumably these experts had some view of what was happening in private industry or abroad). That is not very satisfactory as things within SEDs framework modeled as varying or stochastic (e.g. climate policy, energy prices) will elicit more or less R&D expenditures abroad and by private firms. For example, climate policy that priced CO_2 is likely to bring forth a much larger R&D investment from the private sector. The US government has had a policy to challenge other countries to match US R&D expenditures. These considerations are obviously critical in gauging where US Federal Energy R&D dollars should go. For many good reasons, economic research on technology and technical change usually sees a stronger role for Federal expenditure on more basic research where the social return to R&D expenditure is likely to exceed significantly the private return because of the non-appropriability of these returns—i.e. inability to effectively protect intellectual property—and a larger role for the private sector, and smaller role for the Federal government, as the technology moves to the development, demonstration, and

dissemination phases where returns are more likely appropriable by the investor through patenting, trade secrets, or learning by doing whose benefits mostly accrue to firms making the investments. However, modeling exercises of this sort will typically provide higher estimates of benefits for technologies that are close to commercialization because a small investment will bring them rapidly to commercialization and therefore bring early economic returns. But these are the exact opportunities that private firms are likely to invest in. Thus, using this raw analysis results from SEDs would likely bias the allocation of Federal funds in the exact opposite direction that economists who study R&D would recommend for the Federal role. I.e. Nearly all economists would see a role for Federal involvement in basic research while many would see little need for Federal involvement in the demonstration and dissemination phases except under special circumstances. Thus, I believe any results drawn from the SEDs framework at this point need to be seen as where are the highest returns for additional R&D *expenditure*—not necessarily *Federal expenditure*. There must be complementary analysis to determine whether that is research and demonstration that the private sector is likely to fund or not (and whether international partners should be sought) and only then determine what this means for allocation of the US Federal R&D dollar. Incorporating other R&D funders into the SEDS analysis framework would be quite difficult, and I can imagine that the data needed so do are limited, and estimating the R&D investment response to higher energy prices or CO_2 taxes is highly challenging. I did not see the expertise on this team to take this on. However, this ought to ultimately be a focus of funding that is supporting the SEDS effort. I.e. The DOE office funding this ought to have a side project, supporting researchers with some expertise on this topic, to investigate how best to bring this perspective into the analysis—whether through enhancement of SEDs, or ancillary analysis. Issues such as this reflect that complexity of the R&D funding issue, and emphasize the fact that no one modeling effort is likely to be able to cover all of these issues. SEDS should go forward but one needs to recognize explicitly where some of the limits and biases might be and correct those through side analysis and use of other models or approaches.

Appendix C.5: Comments of Costa Samaras

General Comments

Overall this is an ambitious effort and good progress has been made. No model will be perfect, but SEDS has the potential to become very useful to DOE decision makers and to the general modeling and research community once the critical issues identified during this review are addressed. The geographically disparate team of SEDS developers representing several different national labs should be commended on bringing SEDS to its current status.

The SEDS client at DOE/EERE should reemphasize and articulate the mission and goals of the SEDS program, so that model developers are designing specifically for that set of objectives. Developers and the client should continually be asking the question if a requested additional piece of information could dramatically change the results, with an eye on optimizing a nimble model that yields actionable results.

Going forward, an integrated management and development plan should be initiated to ensure greater cohesion and consistency between the efforts of the model developers. This can take the form of increased face-to-face meeting between the developers. In addition, it is apparent that individual model developers need to become more familiar with the main inputs and outputs of other modules, to improve their own modules so that internal consistency across SEDS can be maintained. The team should consider tasking developers with creating a living documentation of each individual model, either in text or as a wiki. These documentations would detail references, assumptions, methods, inputs and outputs of each module, and would eventually be the foundation for any SEDS-wide documentation. These documentations should be much more detailed than the existing documentation on the SEDS website. In the interim, it would be helpful for the model manager to review these updated documentations on a semi-annual or quarterly basis and provide feedback and check for inconsistencies. Also, consider tasking each module developer with reviewing the documentation of one or several of the other modules.

Besides the comments of the other reviewers, below I provide some general thoughts and individual points addressed to specific modules.

- How do we know which sensitivities are coupled?
    - There have been wide efforts to perform cross-cutting research and mitigate some of the “stovepipe” effects inherent in R&D. If designed correctly, the SEDS module could identify which technologies and outcomes are coupled with each other and with other variables, so that major sensitivities and correlations are discovered and addressed. An example that is not currently in SEDS is energy storage as an R&D pathway that yields spillover benefits across renewables and transportation and others. Capturing the value of spillovers is essential to long-term R&D planning.
- Think about Black and Golden Swans

    - Because of SEDS' unique capability to characterize multiple uncertainties, additional attention on the risks of surprise is warranted. If the model is using a 40-year or more time frame, a surprise event could severely impact (either positively or negatively) the results of the model.

- Need to consider and allocate life cycle impacts that would not be captured or correctly allocated in the economy- land use change etc. from biomass, natural gas extraction and pipeline emissions (fugitive), hydrogen production, electrified transportation, etc. These will influence decision making and results.
- Need to attempt to consider infrastructure feasibility of model results- pipelines (h2, ethanol, other), transmission, water, etc.

Walter Short- Overview

- Total delivered electricity price is different from electricity cost as modeled in SEDS- this will affect decision making
- SEDS could consider the risk of surprise in CO2 tax or economic assumptions
- What happens with a reserve price, banking and borrowing and offsets in carbon policy?
- There is a time step between energy capital price signal and power plant construction, this should be an uncertain variable
- What is the plan to update expert elicitations over time?
- Other policies like a low-carbon fuels standard is important to include
- In Walter's slides- unsure why electricity price is only $25/MWh under a carbon cap?
- Help the R&D decision maker with historical analysis

James Milford- Electricity

- Why can't offshore wind compete? Can this be turned on?
- Static load shape doesn't help look at load shaving/shifting/DSM- this is important for decision making.
- CCS retrofits not included, but consider having this

Chris Marnay- Buildings

- Uniform solar insolation will make you build a lot more solar that would really occur
- What are theoretical limits of roofspace and land in good insolation
- Expert elicitation is a critical input and should be focused on and supported. Look at recent major solar PV elicitation: Curtright, A., Morgan, M.G., Keith, D.W., 2008. Expert Assessments of Future Photovoltaic Technologies. Environmental Science and Technology

Joe Roop- Industry

- Include energy audits as a policy variable?
- To what extent are coal and gas actually fungible in the industrial sector?

- Does the model understand structural changes in the economy? E.g. shift away from manufacturing to services

Anant Vyas and Deena Patel- transportation

- Need a link from macroeconomic factors to ton-miles and vmt
- Why no competition between rail and truck?
- Infrastructure constraints for these big modal shifts that were presented- pipelines, barge traffic, highways

David Greene- world oil market

- What about resource availability?
- Is oil demand between models calculated differently? Need to harmonize and maintain internal consistency

Walter Short- coal and gas

- What about risk of surprise/marcellus shale gas/etc.?
- Need a person to head up this coal/gas unit
- What about coal resource availability- for example see NAS coal report and Dave Rutledge of Cal Tech's coal analysis- www.rutledge.caltech.edu. He predicts that coal supplies are vastly overestimated. This may not be right, but if the chance that he is right is not zero, than this uncertainty (and other low-probability, high impact events) should be included in any characterization of uncertainty.

Max Henrion- Biofuels/Biomass

- Energy and price balance between gasoline and ethanol included?
- EISA 2007 requires 35 Billion gallons of biofuels by 2022
- Need to think about a low carbon fuel standard (LCFS) and indirect land use and land use change issues
- Carbon value of cellulosic needs bounds and should not just assumed to be zero. Could be positive, potentially negative
- Why does an RPS increase biofuel use? Do you mean RFS (or LCFS)?

Deena Patel- Liquid Fuels

- H2 or ethanol pipelines or trucks included? Liquefying and trucking hydrogen is very energy and GHG intensive
    - Where are the GHG boundaries?
- How do the MARS estimates of CO2 from refining differ from GREET?

James Milford- SEDS Demonstration

- Suggest: acronym database and potentially a glossary
- Perhaps the model should save things are you go along as default, instead of having to save each time? Maybe include a list of things you want to save/include?

- Why is the output of GHGs 6000 MMT for the economy instead of the actual ~7000 MMT?
- The top level or home screen of the model should be very simple. Work can be done to improve the usability of the interface

Appendix C.6: Comments of Robert Wallace

I think it is important to make sure that the following things are done for each process technology:

- Make sure that uncertainty distributions are included along the entire supply chain, not just inside the plant gate. The best technology inside the plant gate does not ensure that it has the best chance to be commercialized if the feedstock cost and delivery and the end use delivery and infrastructure are technical barriers.
- In accordance with EISA, any fuel that comes into the marketplace needs to have a GHG reduction from the fossil fuel that it is displacing. Frankly, all of the technologies under the EERE portfolio should be required to have an LCA performed on them in order to get funding to move forward (in some sense). Therefore, I think it is imperative that SEDS includes high level LCA data for each module, with uncertainty.

General comments:

- Energy market are all global markets. If SEDS tries to only capture the US marketplace, it will surely be completely inaccurate. There needs to be some way to represent global energy markets.
- There needs to be a representation of regionality in the model. Each technology has a different regional base and the groups that are providing the information for SEDS should specify it for you.
- The presentations were very good, but not enough time was spent on the discussions that followed.
- The idea of having a desktop model is a good one. However, beware of the unintended consequences of making that decision. By releasing it publically in that form, someone can bastardize it and use it. They can say the results come from a DOE model and if they show negative results, you will spend too much time doing damage control. It does not matter how many caveats you put on the model. I think of the science articles that hit the NYT in 2008 that DOE is still reeling from.

Modeling

- Is SEDS modeling failure? I think it is important to consider this. I know we modeled "Chance of technical success" for the biomass GPRA/PDS project, but only for the biochemical technical barriers. However, failure has a two pronged reaction:
    - It will help R&D because other organizations can learn from the mistakes of the failure, and
    - It can scare off investors, making it harder for the next projects to get financed.
- We looked into modeling failure for the BSM. You might want to speak with Brian Bush to see if it made it into the model.

- How does scale up get modeled for new technologies? Going from the R&D bench to full scale is certainly a recipe for failure. Again, you might want to check the logic that the BSM (and time line) with Brian Bush. I feel they modeled it pretty well.
- It is also important to model design and construction time for new plants.
- There need to be a way to model other advanced biofuels that are being investigated by DOE and those that are not. At the end of the day, if one is making biofuels (or power) from biomass, there is a limited amount of biomass (land) available.
- For technologies that have biomass as a feedstock, it is important to define uncertainty around feedstock availability and price. I truly believe that feedstock and delivery infrastructure will be a bigger bottleneck than the actual technologies that DOE (and others) are addressing.
- Different assumptions surrounding future grid designs will have a huge impact on all types technologies as for market penetration. Are we assuming business as usual for future grid configurations (regional, distributed energy vs. current, long traveling energy from large sources).
- Real market penetration for any technology will be limited by the price of steel, skilled labor, and environmental issues. These are soft, but very important.
- Oil and gas module: The coupling of oil and gas prices neglects the current Marcellus shale natural gas production. Although oil and natural gas should not be completely decoupled, their relationship will certainly not be the same in the future as it currently is.
- Each technology group has a different idea of how R&D dollars will lead to success, and in fact, it will be different for each technology group However, some are not as honest about equating $ to gains and use GPRA and other exercise improperly. You need to be cautious of that.
- Is there a reality check on how past R&D dollars related to success? If that could e obtained, it would help. Fr instance, OBP does a 'state of technology' (SOT) for their conversion processes. Again, I would not say that it is technically accurate, but it is better than nothing.
- For biomass modeling, I have identified many holes in the information SEDS is getting and the entire biomass supply chain that needs to be modeled in order to get accurate results. I would be happy to discuss them with you at length.

Appendix C.7: Comments of Michael Leifman

Many or most of my concerns have been captured either in the general comments or in the comments made by other reviewers, so I'll make only a few points and observations here.

I agree that the model is almost-but-not-quite "ready for prime time," though I'm not sure I see the flaws as quite as fundamental as some of my fellow reviewers. Certainly, there are linkages between modules that need to be strengthened, it seems both in terms of decision-theoretic approach, and actual information passing. But I'm not convinced that the model's being neither a general equilibrium tool nor purely a decision analysis tool is necessarily problematic, and would endorse Hill Huntington's suggestion that some rough approximation of price feedback may be a fruitful middle ground. I do agree that the model does not have adequate structure to capture disequilibria and thus markets need to balance, and I do like the suggestion that prices be exogenous (but stochastic) to achieve that result. Since the model's main objective is to help DOE choose between different portfolios of R&D spending, and one of the metrics used for that purpose is consumer expenditures on energy services, it would be nice to have actual price feedback and ultimate convergence, but for this version of SEDS, a first order convergence suffices.

On the question of R&D outside the walls of DOE: my understanding is that the expert panels are instructed to consider these sources of R&D for the baseline (no federal R&D) case, and that the distributions around DOE goals for the "with federal R&D case" are intended to measure the incremental gains from federal dollars. There is certainly the possibility that Federal R&D will crowd out private R&D, but there is also the possibility that Federal R&D will stimulate deeper private R&D (as patent research has shown). I believe that it's essentially impossible to tease out those two effects at the sub-technology level at which the expert elicitations are done. The model has a learning-by-doing function that is separate from the R&D advances. The LBD's point of departure is the end of the R&D period. <u>*Perhaps*</u> one set of questions to pose for the expert panel could revolve around different learning rates given the absence or presence of federal R&D, but the expertise needed for this question is different from that needed to answer the R&D success question, and thus the work would balloon, as more experts are called upon.

On the question of the logit formulation. I agree that the logit can be slippery, but I don't agree that it's fatally flawed. Andy Kydes suggests a coefficient to indicate a technology preference; this may be a useful enhancement and is worth exploring. It is most certainly true that the choice of the alpha parameter can have a very strong influence on the outcome, and thus a cavalier choice of alpha is dangerous, so I strongly urge the SEDS team to conduct some research on and calibration of, alpha values. This would entail some back-casting, including finding historical cost numbers, and making some judgment calls on what capacity got added for base/intermediate/peak. This is not a trivial exercise, but it's an important one. There is an argument to be made that preferences change over time, and so too the variance suggested by the alpha, and therefore the alpha value should change as well. This may be true, but the logit is no more susceptible to the problem of unknowable changing preferences than any other method, e.g., the WACC of one technology may change given higher or lower risk premia for technology X, but that change would be as unknowable to a cost optimizing agent as to a logit formulation. I also disagree that the logit – if properly parameterized – is necessarily inferior to a purely cost-minimization function. For one, given that the model is at a national scale, a single agent's cost minimization strategy is likely to greatly overstate the low-cost technology penetration and yield unrealistic knife-edge responses. Even with finer geographic resolution, a pure cost minimization routine can be problematic, as different utilities have different strategies, needs, risks and costs, and SOME measure of that variability is important to produce verisimilitude. The history of capacity additions does not suggest a winner take all approach, and for the penetration of new technologies, a cost-minimizing agent is likely to understate their possibilities. Between the imperfections of a logit and the imperfections of an LP, there stands a multi-agent approach or a contagion/diffusion approach (with their own imperfections, of course). I'd recommend sticking with the logit but a serious effort to properly calibrate it is needed, and potentially refine it as per Andy's comment. This applies not just to the electric power sector logit, but to all of its uses in SEDS.

Finally, I will reiterate a point made earlier, but one that I think is very important: the need for multi-parametric sensitivity testing is crucial so that modelers and users can understand what the results mean. The multiplicity of uncertainties may be "real," but it is also overwhelming. Some testing a) may reveal that some parameters can be left deterministic without any loss and b) will likely facilitate interpretation and comparison of results.

Appendix D: Notes from General Discussion

THESE ARE FROM THE BREAKOUT GROUPS

- Carbon cap "thermostat" approach would benefit from IAM outputs as an alternative to the straight-line reductions currently assumed.
- Examine oil-gas cross-price elasticities.
- Add ability to set/clarify cost framework for decision-making based on different perspectives – e.g., investor v. social
- Need to consider regional and transmission differences
- Should anticipate "black swan" technologies
- Need to "retain internal consistency" between modules
- Biggest weakness is integration of the system – theoretical consistency
- Underestimating the value of R&D because not adaptive
- Use imports/exports to meet supply demand equilibrium and call the model a partial equilibrium
- Correlation exists between high economic growth and oil prices
- Need stochastic macroeconomic outputs
- Simplify oil module but retain demand driver
- Carbon cap linear reduction assumption should change
- Electricity price based on average misleads end use sector investments
- Needs consideration of transmission
- Need consideration of regional differences
- Improve consistency amongst modules – economic drivers,
- Distributions on market dynamics needed, e.g. market share, and investment criteria
- Need to be consistent in learning by doing across technologies
- There may be correlation in learning, just because you are in a well-connected world
- Link next year industrial demand to GDP
- Separate refining from industry
- Explicitly consider investor risk/uncertainty in the market share algorithms

FROM GENERAL DISCUSSION DURING THE PRESENTATIONS/LUNCH

- GTL needs to be included
- Need to include biofuels other than ethanol
- Need to add offshore wind
- Load shape needs to be dynamic, especially to capture PHEVs
- Consider retrofits of CCS to existing power plants
- Consider having plants change to lower capacity factor LDC slices with aging
- Consider modeling failure of new plant types
- Consider estimating logit parameter statistically
- Consider correlations between technologies
- Consider tying service demands to GDP
- Add Demand response
- Consider mass transit
- Consider R&D impact on water transport
- Consider competition between rail and heavy duty
- Consider connecting farm and off highway to biofuels
- Consider tying disruption probability to the EIA oil projection used (Low, med, hi)
- Consider that price swings caused by more than just disruptions
- Why not have a prob distribution on oil price with some response to US demand
- Consider a simple autoregressive model with drift
- Consider adopting EIA's relationship between oil and gas
- Consider including gas ties to international markets which will get stronger over time
- Consider Incorporating improvements in technology that can increase coal and gas supply
- Consider adding microalgae
- Consider biofuels imports
- Consider using a more integrated resource model than Polysys
- Consider re-estimating carbon emissions associated with corn ethanol
- Consider directly addressing the chicken and egg issue of H2 infrastructure
- Check as to whether we can really sell gasoline overseas – are we competitive?
- Make Analytica automatically prepare comparisons of different sensitivity runs
- Make it easy to do "importance" analysis
- Include banking of carbon allowances; otherwise costs can be higher by 50% - 100%